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Testing Fuel Efficiency of Tractors with both Continuously Variable and Standard Geared Transmissions

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TESTING FUEL EFFICIENCY OF TRACTORS WITH BOTH CONTINUOUSLY VARIABLE AND STANDARD GEARED TRANSMISSIONS

by

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Testing Fuel Efficiency of Tractors with both Continuously Variable and Standard Geared Transmissions

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A John Deere 8295R IVT tractor with a continuously variable transmission (CVT) and a John Deere 8295R PowerShift (PST) tractor (Waterloo, Iowa) with a standard geared transmission (GT) were tested for fuel consumption at three different travel speeds with six different load levels applied per speed. The JD 8295R PST tractor was tested both at full throttle (FT) and shifted up two gears and throttled back (SUTB) to achieve the same travel speed as at full throttle conditions. The three speeds tested corresponded to the maximum speeds achieved in 6th, 8th and 10th gear for the JD 8295R PST tractor at FT. The six load levels corresponded to 30%, 40%, 50%, 60%, 70% and 80% load at maximum power for each selected gear as determined from the unballasted portion of the official OECD Code 2 test (OECD, 2010) for the JD 8295R PST tractor (NTTL, 2010). Linear regression analysis was performed and the results showed that the tractor with the CVT was more fuel efficient than the tractor with the GT at FT when the power was below 76% to 81% of maximum drawbar power depending on the travel speed. The results also showed that above 37% to 52% of maximum drawbar power, the GT at SUTB was more fuel efficient than the CVT equipped tractor. As travel speed increased, the percent of maximum power below which the CVT was significantly more fuel efficient than the GT at FT decreased slightly. Likewise, the percent of maximum

power above which the GT at SUTB was more fuel efficient than the CVT decreased as speed increased. Additional testing is needed on other models of tractors from other manufacturers to determine whether the trends found in this study pertain to all CVT equipped tractors or if they are specific to this tractor model and manufacturer.

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1 Introduction

Testing tractors to make sure that they meet their advertised performance claims has been a central focus of the Nebraska Tractor Test Lab since the Nebraska Tractor Test Law passed in 1919. Besides making sure that tractors meet their advertised performance claims, the standardized test protocol developed as a result of the law allowed a means of comparison between tractors of different makes and models, as well. Since 1919, tractors have advanced significantly and are now available with numerous options.

One of these options for some tractors is the choice of different transmissions. Many tractor models are now available with both standard geared transmissions (GTs) and continuously variable transmissions (CVTs). Unlike traditional geared transmissions that operate using a series of fixed gear ratios, CVTs have the ability to operate over an infinite number of gear ratios within a certain range. They are equipped with control systems that have the capability to adjust the transmission ratio and engine output to operate at the point of maximum fuel efficiency for the given conditions.

There is currently only a minimal standardized test protocol in place that allows the comparison of fuel efficiency between tractors that are available with both CVTs and GTs at settings other than full throttle. Furthermore, most standardized drawbar testing is currently done at or near maximum power where GTs have been shown to be more fuel efficient (Coffman et al., 2010). A test procedure that compares fuel efficiency between these two types of tractors over a range of loads would provide useful information both for the consumer looking to buy a new tractor and to the manufacturer who is looking to advertise the benefits of the different transmission options available.

1.1 Objectives

The goals of this research were (1) to determine the partial load level at which statistically significant fuel consumption differences occur between the tractor equipped with the CVT and the tractor equipped with the GT operated at full throttle (FT), (2) to determine the partial load level at which statistically significant fuel consumption differences occur between the tractor equipped with the CVT and the tractor equipped with the GT operated under “shift-up-throttle-back” (SUTB) conditions, (3) to determine if significantly different fuel consumption results are obtained when different travel speeds are tested and (4) to recommend an optional test procedure that can be added to the OECD Code 2 for determining the fuel efficiency of a CVT transmission at varying drawbar load levels.

2 Literature Review

The concept of the CVT, which is described in Renius and Resch (2005), is based off of the “shift-up, throttle-back” (SUTB) or “gear up and throttle down” approach to driving a conventional geared transmission as described in Grisso and Pitman (2009). If less than full power is required, the same amount of required power can be developed with increased fuel efficiency by using a lower engine speed and a higher gear ratio. The CVT, ideally, is capable of giving the same performance as a standard geared transmission operated under SUTB conditions, but without the operator having to experiment to find the optimum gear/throttle position combination. The CVT has the additional advantage over the GT of being able to choose a more efficient transmission ratio than the limited discrete ratios available with GTs.

2.1 Current Testing Practices

Since the Nebraska Tractor Test Law was first instituted in 1919, there has been continuous development in tractor testing including the worldwide standardization of tractor testing to ensure that the results from tests done in different locations and times are comparable. The Organization for Economic Co-operation and Development (OECD) is one group that oversees the development and maintenance of world-wide tractor testing standards. Currently, the OECD Code 2 standard for official testing of agricultural and forestry tractors (OECD, 2010) is globally used as the standard by which tractors are tested. Since, most of the tests performed under OECD Code 2 are done at maximum power, CVTs have no significant fuel efficiency advantage over standard geared transmissions when tested according to OECD Code 2.

Efforts have been made to develop a test procedure for comparing the fuel efficiency of tractors equipped with standard geared transmissions and CVTs. Coffman et al. (2010) performed drawbar testing on a John Deere 8530 IVT tractor in both manual and automatic modes. The tests were performed with the throttle set to wide open, so with the transmission in manual mode, the engine speed was at maximum. With the transmission in automatic mode, the CVT controlled the engine speed to achieve maximum fuel efficiency for the given load. The intended travel speed was set to 9.0 $km \cdot h^{-1}$ (5.6 mph) with the actual average travel speed being measured at 7.27 $km \cdot h^{-1}$ (4.52 mph). A total of 17 different loads, ranging from 50% to 90% of the maximum power load at rated engine speed, were applied in three randomized sequences. From this study, it was found that the order in which the loads were applied did not affect the steady state results. Also, the CVT in automatic mode was more efficient than the CVT in manual mode at loads less than 78% of maximum power at rated engine speed when the throttle was set to maximum. However, the performance of a CVT transmission operating in manual mode may not be the same as the performance of an actual geared transmission.

The German Agricultural Society (DLG) Test Center (Groß-Umstadt, Germany) has been developing a new test that can account for varying drawbar loads, PTO loads, and hydraulic loads all at the same time (Degrell and Feuerstein, 2005). This test, named the “DLG-PowerMix,” uses 8 different load cycles to simulate the entire range of uses for an agricultural tractor. Each load cycle consists of a dynamic load curve that is applied over a fixed amount of time that can incorporate drawbar pull, PTO torque, hydraulic power, or any combination of the three depending on the type of work simulated.

Theoretically, this test, using a drawbar loading, could compare the fuel efficiency between a tractor equipped with a standard geared transmission and a tractor equipped with a CVT. However, due to the dynamic load curve, it would be very difficult to replicate the test using a different load car (at a different test station) due to differences in the load car controllers and components. Also, the load cycles that DLG has chosen may not be appropriate for typical North American row-crop farming operations.

2.2 Tractor Loading

In typical farming operations a single tractor may pull a variety of different implements with varying power requirements. Research has been conducted that illustrates the average power required to pull certain implements. Rickets and Weber (1961) conducted research to study the engine horsepower output of a single tractor for several farm operations. They found that operations that farmers generally called heavy work varied from 56 to 97 percent of the maximum horsepower available from the tractor at full throttle. Also, lighter applications such as raking could range as far down as 20 percent of maximum power. Speeds ranged from 2.9 $km \cdot h^{-1}$ (1.8 mph) for combine harvesting to 19.3 $km \cdot h^{-1}$ (12 mph) for rotary hoeing, however, most drawbar applications fell into the range of 5.6 $km \cdot h^{-1}$ (3.5 mph) to 10.0 $km \cdot h^{-1}$ (6.25 mph).

Research was performed by McLaughlin et al. (2008) to determine the energy inputs for eight primary tillage implements applied to a clay loam soil over a four year period (2002-2005). The eight primary tillage implements included deep zone till, moldboard plow, chisel sweep, disk ripper, chisel plow, shallow zone till, fluted coulter, and disk harrow. The tractor used for this testing was a Case IH 7110, which had a maximum drawbar power at rated engine speed rating of 86.5 kW (116.5 hp) from the factory (NTTL, 1988). The range of the tractor-implement matches was considered by the authors to be "typical" of that found on many farms. Using the provided values for implement width, average forward speed, and average draft, the average power required to pull each implement was calculated. The calculated average power values ranged from 22.8 kW (30.6 hp) for the disk harrow to 70.4 kW (94.4 hp) for the deep zone till and a total average power of 44.5 kW (59.7 hp). These values correspond to a range of 26.4% to 81.4% of available tractor power with an average value of 51.5%. For this study, speeds varied from 5.1 $km \cdot h^{-1}$ (3.2 mph) to 7.5 $km \cdot h^{-1}$ (4.7 mph).

Changing soil conditions and topography play a significant role in determining the required drawbar power. One study on the spatial mapping of tillage energy (McLaughlin and Burt, 2000) showed that the draft force required to pull a combination disk-ripper varied significantly with respect to location in an agricultural field composed of clay-loam soil. Using the spatial maps generated from this study of the draft forces and the measured ground speeds produced through the field, the maximum and minimum power required could be calculated. The maximum draft force fell into the 25.6 kN (5760 lb) to 46.0 kN (10300 lb) range and occurred predominantly at the northwest corner of the field. The minimum draft force was in the 0.0 to 20.0 kN (4500 lb) range and occurred predominantly at the northeast corner of the field. From these figures, an average maximum value of 35.8 kN (8050 lb) and an average minimum value of 10 kN (2250 lb) were found. The speeds corresponding to these locations were found to be in the ranges of 0 to 8.10 $km \cdot h^{-1}$ (5.03 mph) for the maximum draft force and 8.28 $km \cdot h^{-1}$ (5.14 mph) to 9.14 $km \cdot h^{-1}$ (5.68 mph) for the minimum draft force, leading to maximum and minimum ground speed values of 4.50 $km \cdot h^{-1}$ (2.80 mph) and 8.71 $km \cdot h^{-1}$ (5.41

mph), respectively. Using the average force and speed values determined from the spatial maps, the average maximum and minimum powers were found to be 40.3 kW (54.0 hp) and 24.2 kW (32.5 hp), respectively. The tractor used for the work was a Case IH 7110, which as mentioned earlier had a maximum drawbar power at rated engine speed rating of 86.5 kW (116.5 hp) from the factory (NTTL, 1988). Knowing this, it was calculated that the average maximum percentage of full power used was 46.6% and the minimum percentage of full power used was 28.0%. Due to the fact that averaged values were used from the spatial plots, the calculated maximum and minimum power values are most likely lower and higher, respectively than the true maximum and minimum power values required to pull the disk-ripper.

Several other researchers have mapped soil mechanical resistance in agricultural fields with corn-soybean rotations. By studying the spatial maps generated for this research (a similar procedure as that used for tillage energy study), several ratios of minimum-to-maximum soil resistance values have been found. Results in Chung et al. (2008) showed minimum-to-maximum soil resistance ratios of 0.57 and 0.64. Results in Siefken et al. (2005) showed a minimum-to-maximum soil resistance value of 0.50 in fields that had previously been no-till. Likewise, results in Adamchuck et al. (2008) showed minimum-to-maximum soil resistance values of 0.45 and 0.55 for a field that had been in a no-till rotation for more than ten years. The types of soil varied widely for these studies and the minimum-to-maximum soil resistance values reported here are most likely slightly lower than what was actually experienced in the field due to the fact that averaged values from spatial maps were used to calculate them. However, between the tillage energy study and the soil mechanical resistance studies, it was demonstrated that the amount of power needed to pull an implement can vary greatly within a field.

3 Materials and Methods

3.1 Design Concept

The overall goal of this investigation was to develop a test procedure to compare fuel efficiency between tractors equipped with CVTs and tractors equipped with GTs. A dynamic testing scenario similar to an EPA emission certification test in which the engine is operated during a series of dynamic cycles to simulate different driving conditions was considered. The tractor loading cycles would have been chosen to simulate differing field conditions. With a dynamic cycle, there is a possibility for interaction between the test car load controller and the tractor transmission controller which could possibly lead to different results depending on which test car or load controller was used. Therefore, to more closely follow OECD CODE 2 standards, it was decided to use a steady state approach to testing so that the test results could be replicated no matter what test car is used to do the testing.

3.2 Test Development

3.2.1 Test Design

There are two main ways of operating a standard geared transmission. The first is to simply pick the gear that will give the desired travel speed when the engine is at full throttle, and operate at full throttle. The other method is to select a gear that will give the desired travel speed with the engine at a reduced throttle setting but still with enough power to pull the load. The CVT transmission is designed to automatically and continuously select the optimum engine speed to maximize fuel efficiency and to produce the desired travel speed through the field. Therefore, it was decided to compare two different tractors with three different modes of tractor operation: 1) standard geared transmission with engine at full throttle (GT at FT), 2) standard geared transmission shifted up two gears and throttled back (GT at SUTB) to achieve the same forward speeds as in (1), and 3) CVT in automatic mode with set point travel speeds set to achieve the same speeds as in (1). The decision to shift the GT tractor up two gears was recommended by the manufacturer and also approved by the Nebraska Tractor Test Laboratory.

During the literature review it was determined that tractors are commonly used for applications requiring substantially less than full power. Also, while pulling a certain implement through the field, the required power to pull the implement can vary significantly depending on the soil conditions. For these reasons it was decided to test the tractors at six load levels ranging from 30% to 80% of drawbar load at maximum power in 10% increments. There are already required tests in place that test the tractors at maximum power so it was deemed unnecessary to test the tractors at maximum power again.

A speed range of 5 $km \cdot h^{-1}$ (3 mph) to 11 $km \cdot h^{-1}$ (7 mph) was chosen to encompass a wide variety of field applications. It was decided to pick three speeds out of this range for testing. Three speeds and six loads gave a total of 18 treatment combinations. To implement these treatment combinations, a Split-Plot Design with the whole plots arranged in randomized complete blocks was used. The main plot factor was speed and the subplot factor was load. Four replications were achieved by blocking by time. The resulting test matrix is shown in Table 3.1.

Table 3.1: Test Matrix for CVT fuel efficiency testing.

Day 1: Standard geared transmission in full throttle mode (GT at FT)												
Block	1			2			3			4		
Speed	1	2	3	1	3	2	1	2	3	3	2	1
Load Setting	6	3	5	4	4	4	5	5	6	6	6	1
	4	1	2	2	2	6	1	1	1	1	1	4
	1	2	4	3	6	5	2	4	3	5	3	2
	3	5	1	6	1	3	4	3	4	2	5	6
	5	6	6	1	5	2	3	6	5	3	2	3
	2	4	3	5	3	1	6	2	2	4	4	5

Day 2: Standard geared transmission in shift-up, throttle-back mode (GT at SUTB)												
Block	1			2			3			4		
Speed	3	2	1	3	2	1	1	2	3	1	3	2
Load Setting	6	5	5	2	5	3	6	1	5	2	6	6
	1	2	4	1	6	2	3	2	2	3	2	1
	4	1	1	4	2	5	5	4	1	5	4	4
	2	6	6	5	1	6	1	5	3	1	1	3
	5	3	2	3	4	4	4	6	4	6	5	2
	3	4	3	6	3	1	2	3	6	4	3	5

Day 3: CVT in automatic mode												
Block	1			2			3			4		
Speed	2	3	1	1	3	2	1	2	3	2	1	3
Load Setting	1	6	3	2	4	5	1	6	3	3	3	5
	5	4	4	3	5	4	2	5	6	6	2	1
	2	3	6	5	2	3	4	2	4	1	4	4
	4	1	5	6	1	2	6	4	5	4	1	6
	3	2	2	1	6	6	3	3	1	2	6	2
	6	5	1	4	3	1	5	1	2	5	5	3

As shown in Table 3.1, it was decided to test the standard geared transmission with the engine at full throttle first to obtain the set point speeds for the other two modes tested. The standard geared transmission in shift-up, throttle-back mode was tested next.

The main reason for this is that it was decided to use the same tires for the entire test, and to save time and money, the wheels were switched between tractors the minimum number of times. By using the same tires for the entire procedure, no differences in the coefficients of friction were introduced during the entire test. Also, tractors are generally only tested one per day to avoid delays resulting from warming up the tractor and load car to operating conditions every time tractors are switched.

3.2.2 Test Location

The concrete test track of the Nebraska Tractor Test Laboratory, located in Lincoln, Nebraska (40° 49’ N, 96° 40’ W), with an elevation of 355 m (1165 ft) above sea level, was used for this testing. This site was chosen to satisfy the OECD Code 2 (OECD, 2010) requirement that all drawbar testing on wheeled tractors be carried out on a “clean, horizontal, and dry concrete surface,” so that comparable results can be attained no matter where the testing is done. The test track, which is shown in Figure 3.1, has 243.84 m (800 ft) straight sections that are long enough to achieve multiple steady state runs per side.

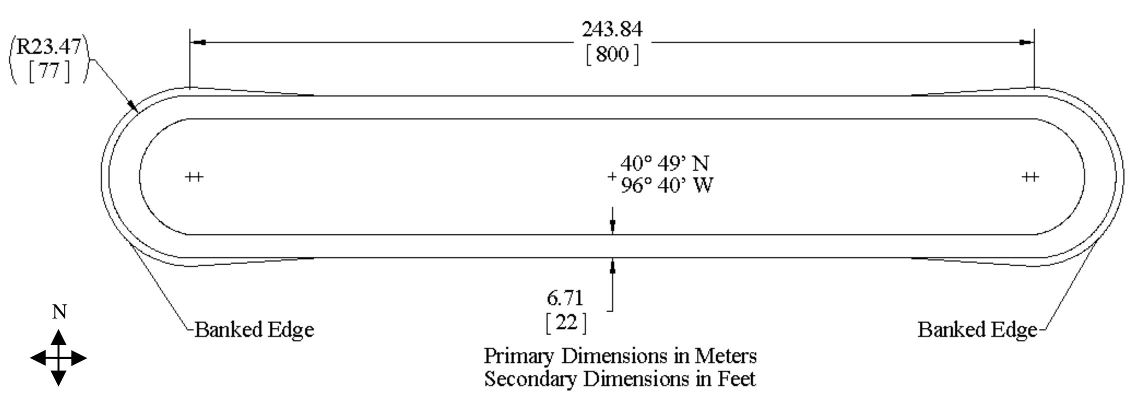

Figure 3.1: Test Track at Nebraska Tractor Test Laboratory, Lincoln, NE.

Performing the testing at the Nebraska Tractor Test Laboratory also allowed access to the instrumented test car and load units used in official OECD testing. It was thought that using the same test equipment along with the same test track that was used for the official testing of the tractors would allow for very comparable results between this testing and the official OECD testing.

3.2.3 Vehicle Selection

The John Deere 8295R PowerShift (PST) and Infinitely Variable Transmission (IVT) tractors were used for testing. The choice of tractors was largely based on availability, but the tractors also had to be identical in every aspect except for the transmissions (minus cab options). The JD 8295R PST and JD 8295R IVT tractors were already at Nebraska Tractor Test Laboratory for official testing during the time frame that this testing was to take place. Deere and Co. (Waterloo, Iowa) donated the use of these tractors, following the completion of the official testing.

The tractors were ballasted in a common ballast configuration of about 75 kg/PTO-kW (125 lb/PTO-hp), which corresponded roughly to a medium draft speed as specified by the tractors' operator manual (Deere and Co., 2009). To achieve this ballasting, the front weight bracket weighing 170 kg (370 lb) was installed on these tractors. Nine QUIK-TATCH™ weights weighing 47 kg (104 lb) each were mounted on the front weight bracket for a total of 593 kg (1,310 lb) mounted on the front of each tractor. Also, two 635 kg (1,400 lb) weights were mounted on the rear axle of both tractors (one on the inside of the inner wheel on both sides of the tractor). To make up for the 272 kg (600lb) lighter weight of the PST transmission, the 8295R PST also had four 75 kg (165 lb) weights mounted on the rear axle (two on the outer side of the outer dual on both sides of the tractor). With this ballasting configuration, the tractors weighed in at 13,640 kg (30,075 lb) for the 8295R PST and 13,580 kg (29,945 lb) for the 8295R IVT with both tractors having 41%/59% weight splits. That is, 41% of the tractor weight was on the front axle and 59% of the tractor weight was on the rear axle. The tractor weights were set as close as possible to each other given the available weights and mounting locations.

The tire pressures were also set according to the manual and were 165.5 kPa (24 psi) in the front tires and 89.6 kPa (13 psi) in the rear tires. The tractor was configured with Goodyear Dyna Torque Radial tires with duals in the rear and singles in the front. The rear tire size was 480/80R46 and the front tire size was 480/70/R30.

3.2.4 Instrumentation Mounting

The two tractors were instrumented in an identical manner. Type K thermocouples were mounted on the tractors to measure the fuel inlet and return temperatures, the engine coolant temperature, the engine oil temperature, the air inlet temperature to the engine and the hydraulic oil temperature. The fuel inlet temperature was measured upstream of the inlet to the fuel injection pump and was maintained at a temperature of 46 ^{o}C (115 ^{o}F) using a fuel heater mounted on the tractor frame behind the right front wheel. The fuel return temperature was measured downstream of the common rail before the fuel cooler. The thermocouple used to measure the engine coolant temperature was mounted in the top tank of the radiator. The thermocouple used to measure the engine oil temperature was mounted in the drain plug of the crankcase. The air inlet temperature was measured using a thermocouple mounted in the air cleaner. The hydraulic oil temperature was measured using a thermocouple mounted in the drain plug of the transmission.

Banner fiber optic sensors (Model D12E2P6FV, Minneapolis, MN) were used to measure the fan and engine speeds. The fan speed measurement was obtained by fastening one of the Banner fiber optic sensors to the fan cowling with the unit pointed at the fan. A piece of reflective tape was placed on the fan to create a high contrast reflectance area to allow the sensor to measure the fan speed. The sensor for the engine speed measurement was mounted using a bracket that connected to the engine block and was pointed at the harmonic balancer at the front of the engine. Like the fan speed measurement, a piece of reflective tape was also placed on the harmonic balancer. The fan and the harmonic balancer were both painted flat black to maximize the difference in reflectivity between them and the reflective tape.

Spectre pressure transducers (Model 3000, Avon Lake, OH) were used to measure the turbocharger boost pressure and drawbar pull. The boost pressure transducer was located after the intercooler so that the measurement was of “cool” boost. The drawbar load was measured using a custom made hydraulic cylinder in the linkage between the tractor and test car (Figure 3.2). A Spectre pressure transducer mounted on the test car was used to record the pressure in the cylinder. Using the known cross-sectional area of the cylinder, 193.74 cm^2 (30.029 in^2), drawbar force could be easily determined from the pressure measurement.

Rear wheel speed was measured using Servo-Tek optical encoders (Model PMA1, Hawthorne, NJ). These encoders were placed in the “wheel counters” and used to measure both left and right rear axle rotational speeds. Using a constant for the advance per revolution of the wheels, 5.88 m/rev (19.28 ft/rev), the rotational speed was converted into forward speed. The advance per revolution number was determined prior to the testing by counting how many times the rear wheels turned a complete revolution over a known distance (closest full wheel revolution past 152.4 m, 500 ft). The wheel counters were mounted to the tractor using special brackets that bolted to the rear wheel weights, which were mounted inside the rear wheels, as shown in Figure 3.2.

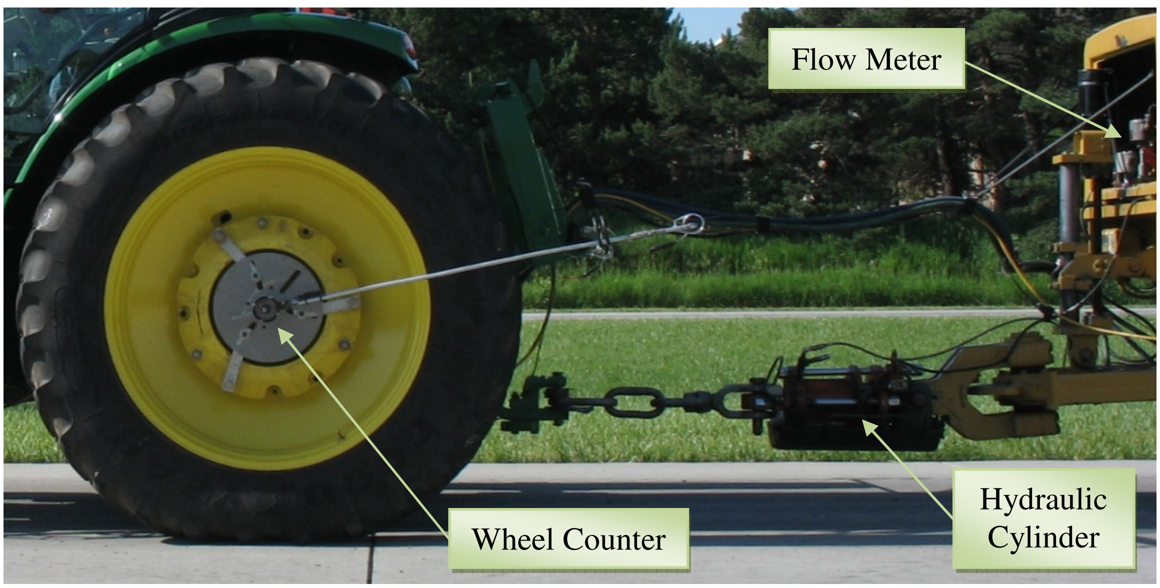

Figure 3.2: Picture including rear of tractor and front of the test car showing the wheel counter mounting location and the hydraulic cylinder used to measure drawbar pull.

Other measurements that were made included the fuel flow rate and actual travel speed. The instrumentation for these measurements was located on the test car. The volumetric fuel flow rate was measured using a MAX positive displacement flow meter (Model 214, Healdsburg, CA) and was converted into mass flow rate using the specific weight of the fuel, 0.842 $kg \cdot l^{-1}$ (7.022 $lb \cdot gal^{-1}$). This flow meter also included an RTD sensor and lookup tables to compensate for changes in specific gravity due to temperature. The flow meter can be seen in Figure 3.2, as well, located right behind the electric actuator used for raising and lowering the tongue of the test car.

The actual travel speed was measured using an unpowered "fifth wheel" with a Servo-Tek optical encoder (Model PMA1, Hawthorne, NJ). The fifth wheel was located behind the cab of the test car and the speed was calculated the same way that the rear wheel speeds on the tractor was calculated. The fifth wheel has an advance per revolution of 1.59 m/rev (5.23 ft/rev). By comparing the actual travel speed with the rear wheel speeds on the tractor, wheel slip was determined.

3.2.5 Data Acquisition and Load Control

The test car, which was a modified Caterpillar articulated dump truck, was equipped with a National Instruments NI PXI 8106 embedded controller running LabVIEW v8.6 (National Instruments Corp., Austin, TX) software for data acquisition, load control and data logging. The controller was mounted in a NI PXI 1042 chassis along with two NI PXI 6602 digital I/O boards, a NI PXI 6255 high speed multifunction data acquisition (DAQ) board, and a NI PXI 2564 general purpose switch module.

One of the NI PXI 6602 boards and the NI PXI 6255 board were used for data acquisition. The NI PXI 6602 board was used to collect engine speed, fan speed, left and right rear axle speeds, and fifth wheel speed through a NI CB-68 connector block. The NI PXI 6255 board was used to read in all of the other measurements. All of the temperature measurements were collected through one NI SCB-68 connector block and drawbar pull and boost pressure were collected through the other NI SCB-68 connector block. A schematic of the data acquisition system is shown in Figure 3.3.

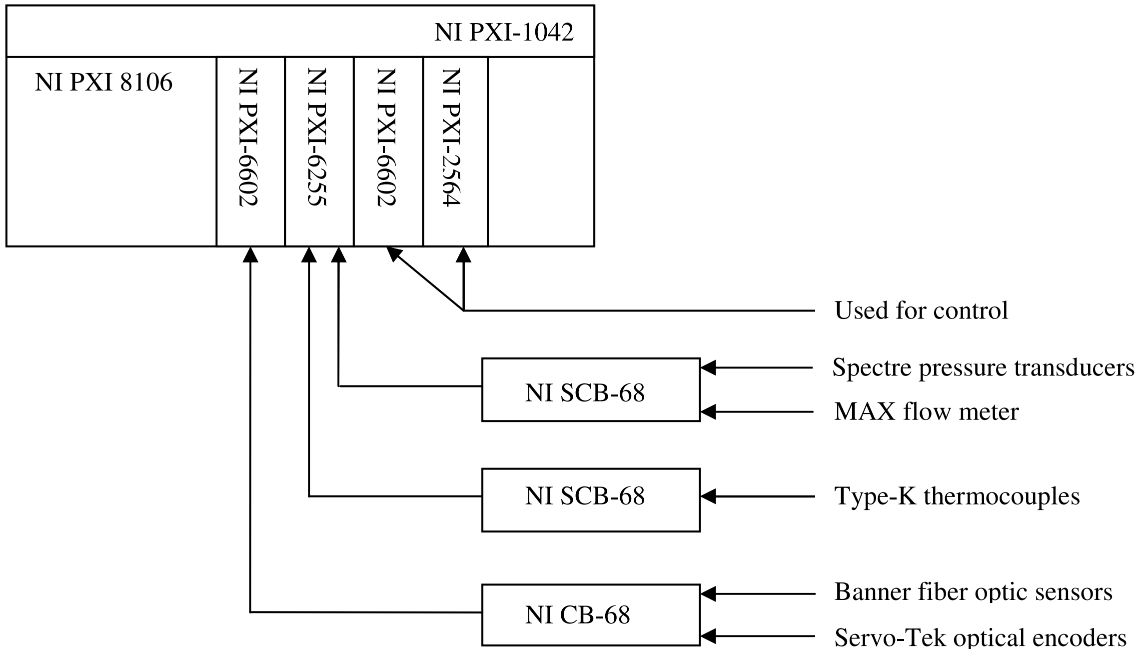

Figure 3.3: Data acquisition schematic.

The NI PXI 2564 module and the other NI PXI 6602 board were used for control purposes. The control system starts with the LabVIEW VI telling the Wineman RIO-100 series PID controller which control method to use and, depending on which control method is selected, converts the feedback (travel speed, drawbar load, or engine rpm) from the data acquisition boards into a 0-10 volt signal that is also passed along to the Wineman PID controller. The Wineman PID controller takes this information and sends out a 0-2.5V signal to the Dyne Systems controller which uses this signal to apply a high current to control the Telma retarders. The Telma retarders are what actually create the load applied to tractor. The retarders apply resistance to the rear wheels of the test car through a gearbox which is attached to the driveline of the vehicle. A schematic of the control system is shown in Figure 3.4.

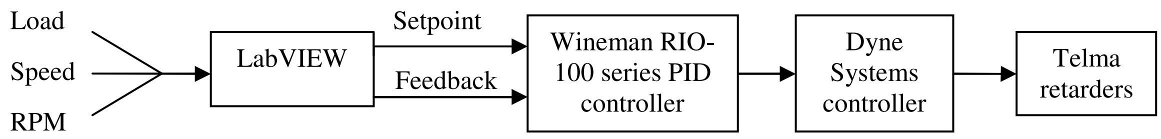

Figure 3.4: Schematic of control system.

The LabVIEW program installed on the test car collected data at a rate of 1 kHz and displayed this data real-time on one computer display. The program also displayed 20 second averages of important parameters and these averages were used by the operator to determine whether the system had reached steady state. The front panel showing the real-time and averaged data can be seen in Figure 3.5.

Figure 3.5: Screenshot of the LabVIEW front panel showing the real-time and averaged values (values shown in figure are not actual test values).

The other computer display showed the front panel containing the control panel as well as the LabVIEW table display of averaged data (Figure 3.6). The computer automatically saved the raw and averaged data into tab delimited files while still taking data. The control panel was the interface the operator used to choose which type of load control to use (speed control, load control, or engine rpm control) and provide inputs for the set point for the desired load setting. The length of data acquisition was also adjusted on this screen. The load control setting was used to perform all testing for this research and the length of data acquisition was set to 60.96 m (200 ft). The LabVIEW table display was used by the operator to check for any erroneous data before moving on to the next load set point.

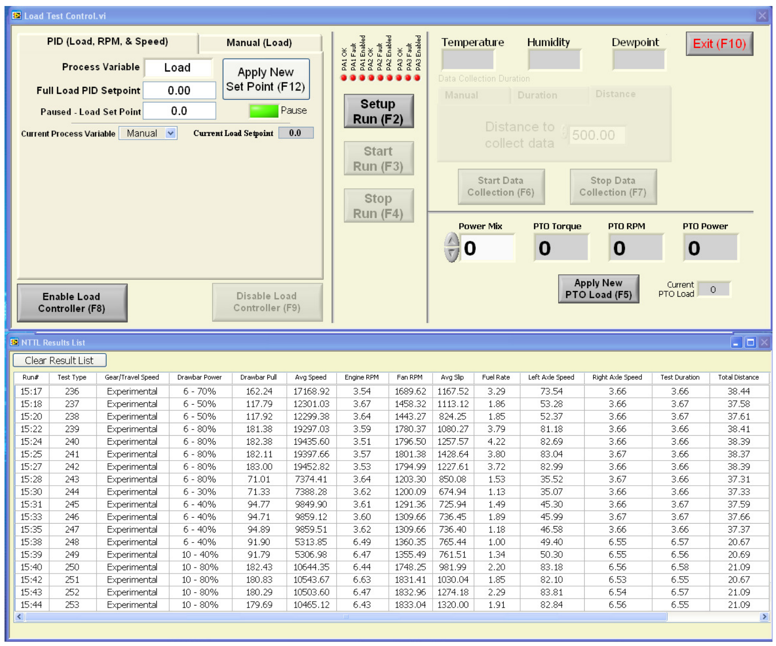

Figure 3.6. Screenshot of the LabVIEW front panel containing the control panel and the table display (note: values in figure are not actual test values).

3.3 Test Procedure

The JD 8295R PST had several gears to choose from that gave a forward speed at full throttle that fell within the range of interest specified earlier for this study. It was decided to use 6th gear, 8th gear, and 10th gear which corresponded to maximum forward travel speeds of 5.94 km·h^{-1} (3.69 mph) for Speed 1, 7.97 km·h^{-1} (4.95) mph for Speed 2 and 10.64 km·h^{-1} (6.61 mph) for Speed 3, respectively. These speeds were used as set point speeds for the GT at SUTB and the CVT in automatic mode. The GT at SUTB was shifted two gears higher than the corresponding gear for the GT at FT for each speed, as recommended by the manufacturer (Table 3.2). The John Deere IVT could only be adjusted in steps of 0.32 km·h^{-1} (0.2 mph) when [mph] was set as the display unit, so the IVT was set as close to the set point speeds as possible and was also set to allow an engine speed range of 1200 rpm all the way up to full throttle using AUTO Mode 3 (Deere and Co., 2009), which was the maximum possible speed range to which the tractor can be set. An excerpt from the operator manual (Deere and Co., 2009) detailing the settings of the IVT can be found in Appendix A.

Table 3.2: Set point speeds and gears used for testing.

Speed Setting	Travel speed (km·h^{-1})	Gear (GT at FT)	Gear (GT at SUTB)
1	5.94	6	8
2	7.97	8	10
3	10.64	10	12

According to the Nebraska Tractor Test 1969 report (NTTL, 2010), the John Deere 8295R PST had a maximum drawbar pull at rated engine speed of 107.40 kN (24,144 lb) in 6th gear, 80.02 kN (17,989 lb) in 8th gear, and 58.42 kN (13,133 lb) in 10th gear. These loads were used to establish the six load settings from 30% to 80% of drawbar load at maximum power for each gear (Table 3.3).

Table 3.3: Load settings for the three different test speeds.

Load setting	% of Load at maximum power	Load (kN)		
		Speed 1	Speed 2	Speed 3
1	80	85.92	64.02	46.73
2	70	75.18	56.01	40.89
3	60	64.44	48.01	35.05
4	50	53.70	40.01	29.21
5	40	42.96	32.01	23.37
6	30	32.22	24.01	17.53

The speed/load combinations were applied in the order shown in Table 3.1. Due to the large amount of load needed for Speed 1, a modified John Deere 5020 was attached behind the load car to increase the available resistive power. The JD 5020 was used to apply extra load by setting the transmission in the appropriate gear for the desired travel speed and allowing the clutch to engage the engine with the fuel off. The test setup is shown in Figure 3.7.

Figure 3.7: Experimental setup showing the John Deere 8295R PST pulling the Nebraska Tractor Test Lab load car with the John Deere 5020 load unit attached behind the load car.

The testing was performed in a clockwise travel direction around the test track. All vehicles traveled on the flat portion of the track, not on the banked portions shown in Figure 3.1. Starting on the south side of the track, the tractor operator was directed to select the correct gear and/or throttle settings to achieve the desired speed and start moving. After the tractor was at the desired speed, the operator of the JD 5020 was directed to engage its transmission and then the load controller on the load car was engaged. At the start of the day, multiple warm-up rounds were completed to make sure that the tractor was at steady state operating conditions before the actual testing was conducted. Steady state operating conditions were met once the hydraulic temperature had reached its normal operating temperature. Once the tractor had reached steady state operating conditions, data collection began with the first load to be applied for the first speed in the first block.

The loads were tested by recording data over a 60.96 m (200 ft) length of straightaway on each side of the track for each load and averaging the results over the entire length. Therefore, two data runs could be taken per straight side of the track, as shown in Figure 3.8. Around the corners, the load car load controller was set to apply a pause load. This pause load was set to the same load as the load being tested, unless that load was greater than 66.72 kN (15,000 lb), to minimize the amount of transition coming out of the corners. For set point loads above 66.72 kN, a possibly damaging amount of side load might be applied to the tractor therefore the pause load was limited to a maximum of 66.72 kN.

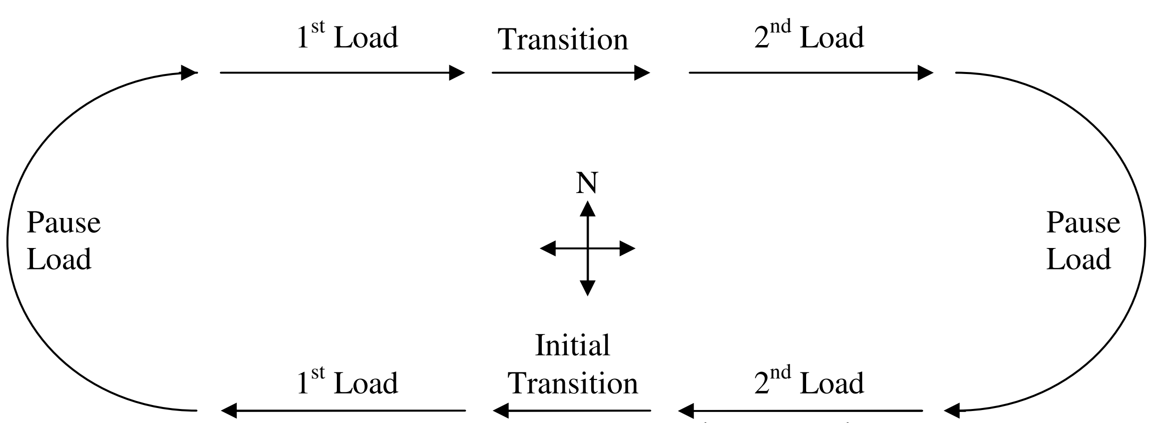

Figure 3.8: Test pattern used (trend continues for 3rd through 6th loads in randomized sequence of each block).

If comparable results were achieved on both the north and the south side of the track, then the next load set point was applied. If the results were not comparable then more data were collected until there was one north and one south run that showed comparable results. Drawbar power and fuel consumption values were used to determine whether the results were comparable or not. If the drawbar power values were within 0.75 kW (1.0 hp) of each other and the fuel consumption values were within 0.23 $kg{\cdot}h^{-1}$ (0.5 $lb{\cdot}h^{-1}$) of each other, then the results were deemed to be comparable. This trend continued until all six loads had been tested.

To test the next speed, the tractor was stopped to allow the test car and JD 5020 to shift into the appropriate gears before continuing testing. The same startup procedure and test procedure as described earlier was used again minus the warm-up laps (the tractor did not cool off much over the few minutes it took to stop and change gears). This procedure continued until the data had been collected for all four blocks of load and speed treatment combinations for the tractor transmission mode.

3.4 Data Analysis

There were small variations in the forward travel speeds at the different loads as well as the different transmission modes. The actual forward travel speeds for speed settings 1, 2 and 3 and the standard deviations are shown in Table 3.4, Table 3.5 and Table 3.6, respectively.

Table 3.4: Actual forward travel speeds for speed setting 1.

Transmission Mode	Max speed ($km\cdot h^{-1}$)	Min speed ($km\cdot h^{-1}$)	Average speed ($km\cdot h^{-1}$)	Standard Deviation ($km\cdot h^{-1}$)
GT at FT	5.94	5.71	5.83	0.086
GT at SUTB	5.94	5.73	5.84	0.085
CVT	5.83	5.68	5.76	0.056

Table 3.5: Actual forward travel speeds for speed setting 2.

Transmission Mode	Max speed ($km\cdot h^{-1}$)	Min speed ($km\cdot h^{-1}$)	Average speed ($km\cdot h^{-1}$)	Standard Deviation ($km\cdot h^{-1}$)
GT at FT	7.97	7.76	7.86	0.081
GT at SUTB	7.98	7.74	7.85	0.093
CVT	7.98	7.87	7.93	0.042

Table 3.6: Actual forward travel speeds for speed setting 3.

Transmission Mode	Max speed ($km\cdot h^{-1}$)	Min speed ($km\cdot h^{-1}$)	Average speed ($km\cdot h^{-1}$)	Standard Deviation ($km\cdot h^{-1}$)
GT at FT	10.64	10.40	10.51	0.091
GT at SUTB	10.64	10.38	10.49	0.107
CVT	10.43	10.38	10.41	0.030

Because speed could not be set consistently at the same value, the relationship between hourly fuel consumption and drawbar power was found using regression analysis instead of Analysis of Variance (ANOVA) or some other approach. The same model was used to fit the fuel consumption curves for all three tractor operating modes for each individual speed and is shown below:

$$Q_i = \beta_0 + \beta_1 \cdot P_i + \beta_2 \cdot M_1 + \beta_3 \cdot M_2 + \beta_4 \cdot P_i \cdot M_1 + \beta_5 \cdot P_i \cdot M_2 + \varepsilon_i$$

where,

Q_i = measured fuel consumption ($kg\cdot h^{-1}$)

$\beta_{0,\ldots,5}$ = Slope ($kg\cdot h^{-1}\cdot kW^{-1}$) and intercept ($kg\cdot h^{-1}$) terms

P_i = actual drawbar power (kW)

M = mode of operation

$$M_1 = \begin{cases} 1\ for\ GT\ at\ FT \\ 0\ otherwise \end{cases}$$

$$M_2 = \begin{cases} 1\ for\ GT\ at\ SUTB \\ 0\ otherwise \end{cases}$$

ε_i = random error

i = 1, 2, 3 corresponding to speeds 1, 2 and 3, respectively

No differences in fuel consumption were found between the blocks so they were dropped from the model, which was implemented using SAS (SAS Institute Inc, Cary, NC). This model allowed the comparison of the differences in predicted fuel consumption values between the GT at FT and the CVT as well as between the GT at SUTB and the CVT. Using an alpha level of 0.05, the power level at which there was a significant difference between the predicted fuel consumption values was determined. The SAS code and output can be seen in Appendix B. The power level at which a significant difference was detected was compared to the maximum power for each speed to find the percent of maximum power at which the significant difference occurred. The percent of maximum power was plotted against travel speed to detect whether there was any trend based on travel speed. In addition to the regression analysis, residual analysis was performed to make sure that the regression model assumptions were not violated.

A similar model was used to compare the predicted fuel consumption values at different travel speeds for each transmission operating mode. Instead of representing transmission mode, the M values represented travel speed:

$$M_1 = \begin{cases} 1 \; for \; Speed \; 1 \\ \\ 0 \; otherwise \end{cases}$$

$$M_2 = \begin{cases} 1 \; for \; Speed \; 2 \\ \\ 0 \; otherwise \end{cases}$$

i = 1, 2, 3 corresponding to transmission modes GT at FT, GT at SUTB, and CVT, respectively

As for the transmission mode comparison, the power level at which there was a significant difference between the predicted fuel consumption values was determined using an alpha value of 0.05. This SAS code and output can also be seen in Appendix B

Once the regression analysis was finished, hourly fuel consumption predictions derived from the prediction equations were compared to results from the fuel consumption portion of the OECD Code 2 test for the JD 8295R PST (NTTL, 2010). This comparison assumed that fuel consumption was not dependent on tractor weight since the OECD test was performed unballasted. The comparison was only made using the prediction equations for Speed 2, since those corresponded to the gear (8^{th} gear) in which maximum power was achieved for the JD 8295R PST and which was used for the fuel consumption portion of the OECD Code 2 test. The comparison was made for full power, 75% of pull at maximum power and 50% of pull at maximum power, although full power was out of the range for which the regression equation was developed. Fuel consumption values from the OECD test at full throttle were compared to the predictions for the GT at FT since they were similar operating conditions. Fuel consumption values from the OECD test at reduced engine speeds were compared to both the GT at SUTB and the CVT since these had similar operating conditions, although for the OECD test, the tractor was shifted up three gears instead of two.

4 System Evaluation

4.1 Pilot Study

There was some concern that travel direction might affect the results since the presence of a tail wind or a head wind could cause variations in fan speed. Also, portions of the track are shaded at certain times of day which might affect the amount of wheel slip achieved. If more power is diverted to turn the fan faster, a decrease in drawbar power might be observed. Likewise, if slip increases then the travel speed is lower and less power is produced. Coffman et al. (2010) found that travel direction did make a difference in fuel consumption, but it was attributed to a 1% slope from south to north (testing done at Lincoln Airport). Although the Nebraska Tractor Test Track is level from east to west, it was decided to perform a pilot study using data from past tractor tests to determine if there was any significant differences between the results obtained from the north and the south side of the track. A simple two-tailed t-test with an alpha level of 0.05 was used to compare drawbar power, drawbar pull, travel speed, engine speed, wheel slip and fuel consumption values from the north and the south side of the track.

4.1.1 Data Collection for Pilot Study

The Nebraska Tractor Test Track was rebuilt during 2007, therefore only tractors tested from 2008 to 2009 were used for this study (no tractors had yet been tested for 2010). Twenty tractors of differing makes and models were found that had undergone drawbar testing during this time frame. Raw track data for the unballasted maximum power runs were obtained on these tractors from the Nebraska Tractor Test Lab and are shown in Appendix C.

4.1.2 Results and Discussion for Pilot Test

The mean, standard deviation and calculated t-statistic for the percent differences of the previously mentioned parameters are shown in Table 4.1. The critical t-value for an alpha level of 0.05 is 2.093 for a two tailed test. The absolute values of the calculated t-values are all less than the critical value, so there were no significant differences between results from the north and the south side of the track.

Table 4.1: Percent differences between data collected from the north and south sides of the Nebraska Tractor Test Track for select parameters.

	Drawbar power	Drawbar pull	Travel speed	Engine speed	Percent slip	Fuel rate
Mean	-0.0008	-0.0013	0.0005	0.0007	-0.0026	0.0019
Std deviation	0.0039	0.0037	0.0013	0.0015	0.0618	0.0144
t-statistic	-0.8897	-1.5900	1.8545	1.9509	-0.1917	0.6036

4.2 CVT Fuel Efficiency Test

4.2.1 Data Collection for CVT Fuel Efficiency Test

The JD 8295R PST operated under full throttle conditions (GT at FT) was tested on June 3, 2010. Shift-up-throttle-back testing (GT at SUTB) was performed on June 4, 2010. The JD 8295R IVT was tested in automatic mode on June 8, 2010, after the wheels on the JD 8295R PST were removed and placed on the JD 8295R IVT and the tractor was weighed and wheel counting was completed. The raw data from these tests can be found in Appendix D. The atmospheric conditions for the duration of the testing can be found in Appendix E.

4.2.2 Results and Discussion for CVT Fuel Efficiency Test

Regression analysis of the relationship between fuel consumption and drawbar power produced the following models for Speeds 1, 2 and 3, respectively:

$$\hat{Q}_1 = 2.565 + 0.250 \cdot P + 5.927 \cdot M_1 - 0.041 \cdot P \cdot M_1 + 2.095 \cdot M_2 - 0.031 \cdot P \cdot M_2$$

$$\hat{Q}_2 = 4.141 + 0.239 \cdot P + 5.236 \cdot M_1 - 0.035 \cdot P \cdot M_1 + 1.051 \cdot M_2 - 0.024 \cdot P \cdot M_2$$

$$\hat{Q}_3 = 5.205 + 0.240 \cdot P + 4.801 \cdot M_1 - 0.034 \cdot P \cdot M_1 + 0.845 \cdot M_2 - 0.024 \cdot P \cdot M_2$$

Separating the modes of transmission operation, these models can be rewritten as:

$$\hat{Q}_1 = \begin{cases} 8.49 + 0.209 \cdot P & \text{for GT at FT} \\ 4.66 + 0.219 \cdot P & \text{for GT at SUTB} \\ 2.56 + 0.250 \cdot P & \text{for CVT} \end{cases}$$

$$\hat{Q}_2 = \begin{cases} 9.38 + 0.204 \cdot P & \text{for GT at FT} \\ 5.19 + 0.215 \cdot P & \text{for GT at SUTB} \\ 4.14 + 0.239 \cdot P & \text{for CVT} \end{cases}$$

$$\hat{Q}_3 = \begin{cases} 10.01 + 0.206 \cdot P & \text{for GT at FT} \\ 6.05 + 0.216 \cdot P & \text{for GT at SUTB} \\ 5.20 + 0.240 \cdot P & \text{for CVT} \end{cases}$$

The measured fuel consumption data and the predicted models are shown in Figure 4.1. The fuel consumption values for the GT at FT and GT at SUTB are practically parallel, with the GT at FT having higher fuel consumption values at all power levels. Since the GT at SUTB will always be more fuel efficient than running at FT, no further comparison was done between these two operating modes. The coefficients of determination (R^2) values for these lines were found to be 0.993 for Speed 1 and 0.995 for Speeds 2 and 3.

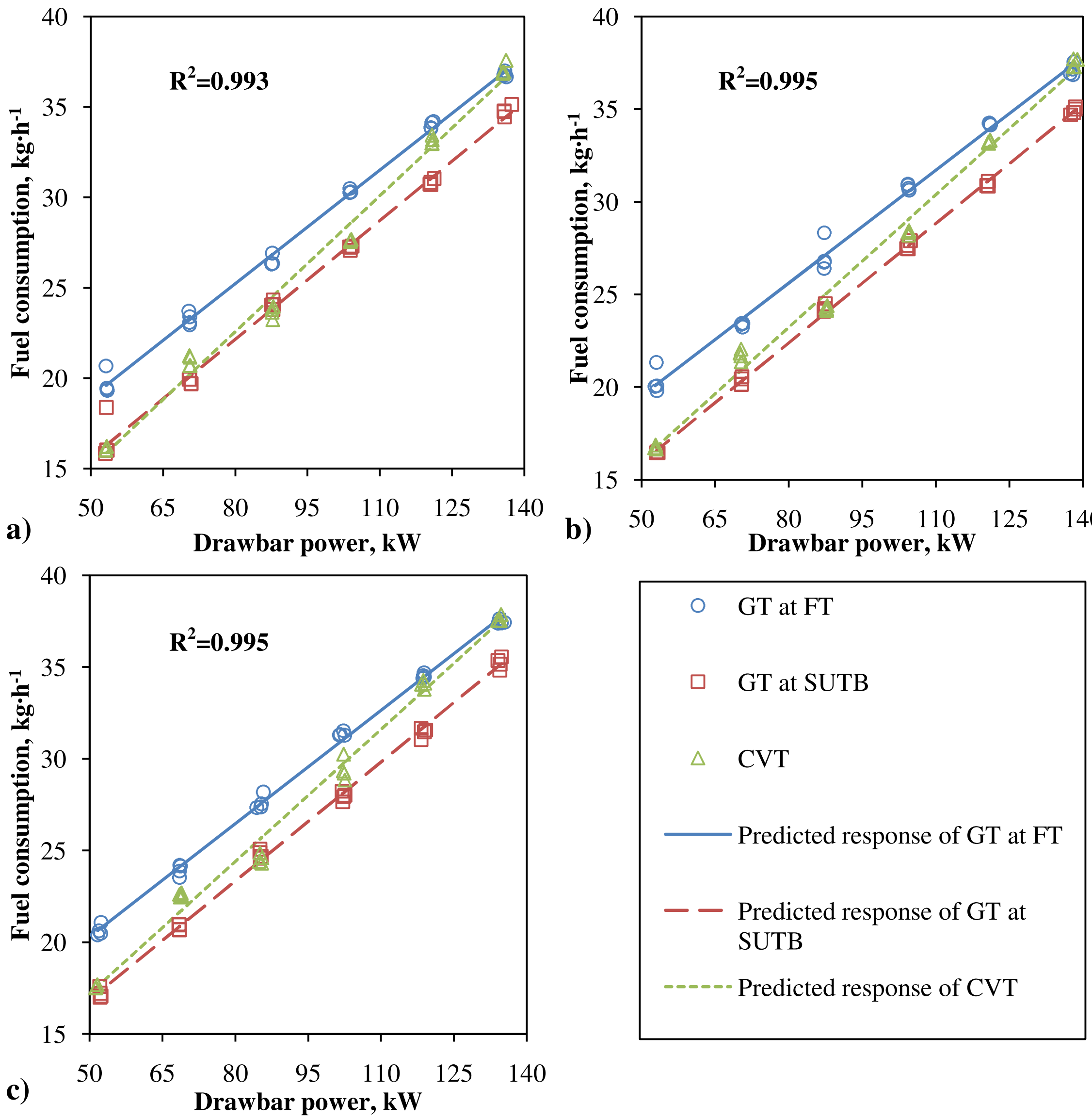

Figure 4.1: Hourly fuel consumption response to drawbar power for a John Deere 8295R PST and a John Deere 8295R IVT at (a) Speed 1, (b) Speed 2 and (c) Speed 3.

The fuel consumption prediction errors at all three travel speeds are shown in Figure 4.2, and based on these values, there did not seem to be any discernable trends with respect to drawbar power.

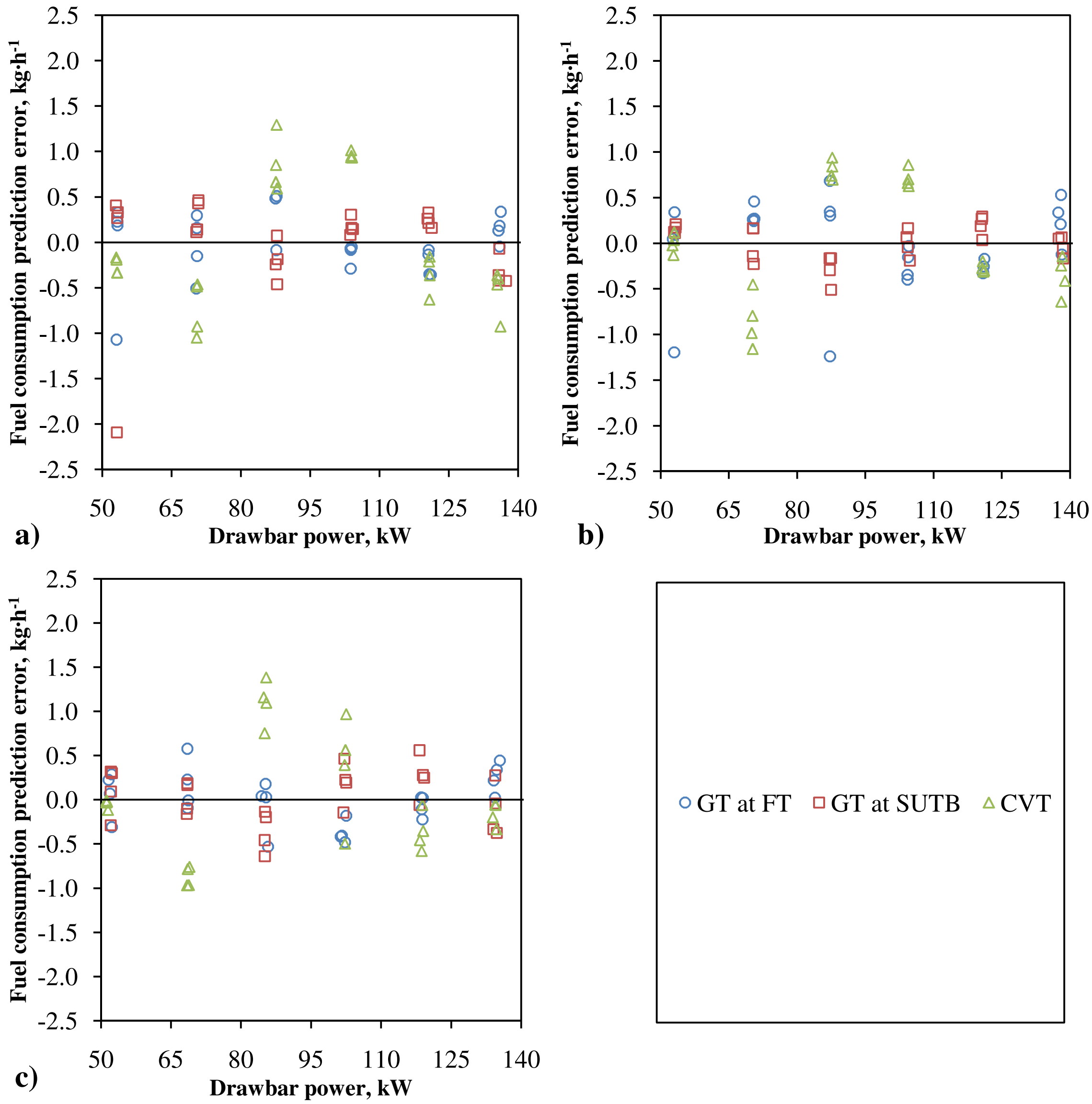

Figure 4.2: Fuel consumption prediction error analysis with respect to drawbar power for (a) Speed 1, (b) Speed 2 and (c) Speed 3.

The difference between predicted fuel consumption values for the three transmission modes as a function of drawbar power was plotted for the three different travel speeds (Figure 4.3). Based on the analysis of difference of fuel consumption between the GT at FT and the CVT in automatic mode, shown in Figure 4.3a, c and e, the fuel savings of using the CVT in automatic mode increased as the power level decreased, but the fuel consumption was similar at higher loads. A comparison of the values of the predicted fuel consumption difference between the GT at FT and the CVT ($\hat{Q}$ for the GT at FT minus $\hat{Q}$ for the CVT) with the 95% confidence interval for this difference showed that the CVT reduced fuel consumption significantly below certain power levels. The CVT was more fuel efficient below 128 kW (172 hp) for Speed 1, 131 kW (176 hp) for Speed 2 and 124 kW (166 hp) for Speed 3, which corresponded to 81%, 79% and 76%, respectively, of the maximum drawbar power obtained during the unballasted portion of the official OECD test (NTTL, 2010), as shown in Table 4.2.

The analysis of difference of fuel consumption between the GT at SUTB and the CVT showed that the GT at SUTB was more fuel efficient at higher loads, but the fuel consumption was similar at lower loads as shown in Figure 4.3b, d, and f. A comparison of the values of the predicted fuel consumption difference between the CVT and the GT at SUTB ($\hat{Q}$ for the CVT minus $\hat{Q}$ for the GT at SUTB) with the 95% confidence interval for this difference showed that the GT at SUTB had significantly lower fuel consumption above certain power levels. The GT at SUTB became more fuel efficient above 82 kW (110 hp) for Speed 1, 66.5 kW (89 hp) for Speed 2 and 60 kW (80 hp) for Speed 3, which corresponded to 52%, 40% and 37%, respectively, of the maximum drawbar power obtained during the unballasted portion of the official OECD test (NTTL, 2010), as shown in Table 4.2.

In general, the CVT was more fuel efficient than the GT at FT and the GT at SUTB was more fuel efficient than the CVT within the range tested. Normal field operations will generally require 50% to 80% of maximum power and in this range, the GT at SUTB is generally going to be the best option, if the fuel use data is displayed to the operator and if the operator is actively engaged in choosing gears and throttle settings.

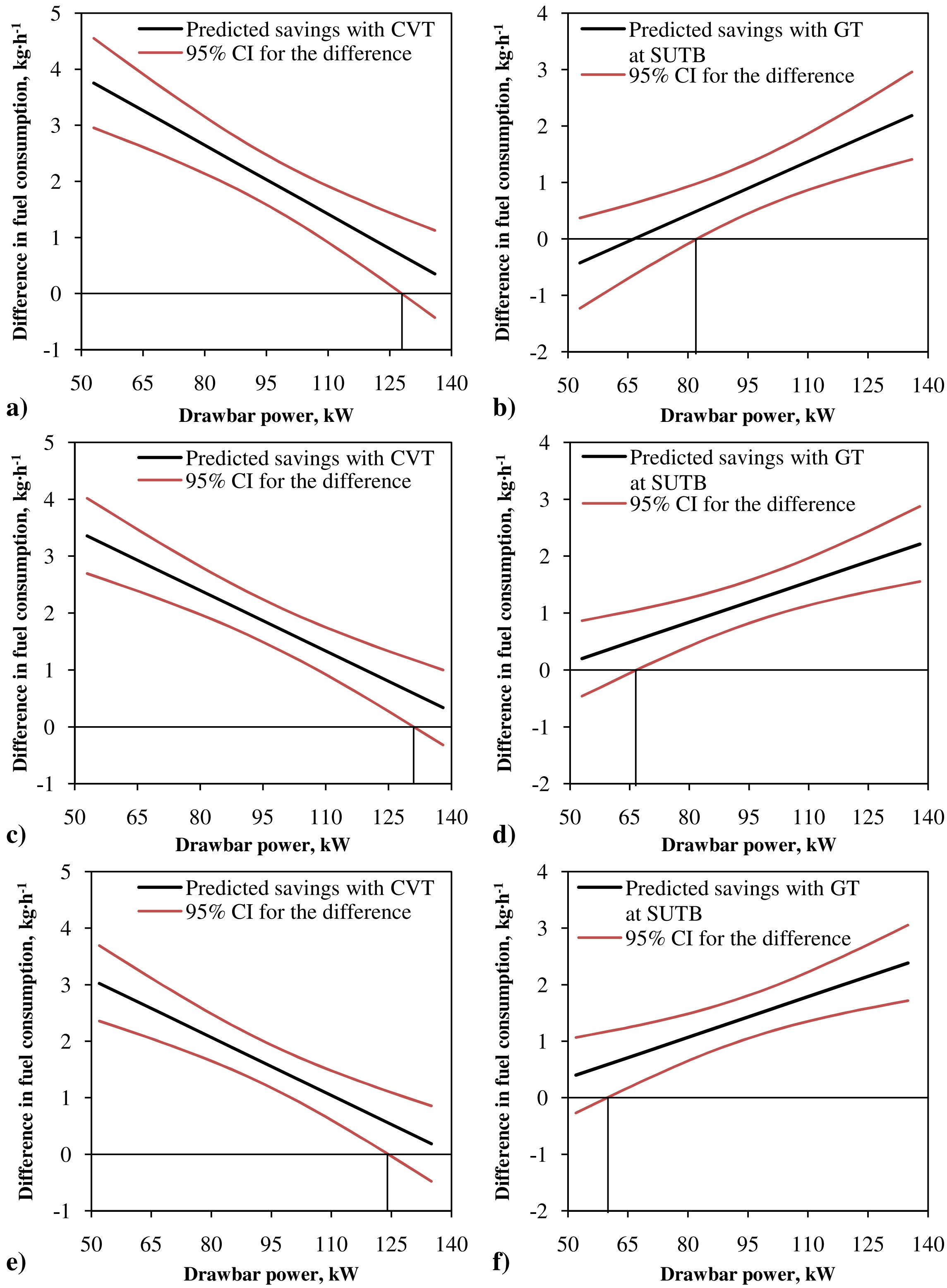

Figure 4.3: Difference in hourly predicted fuel consumption response to drawbar power between the GT at FT and the CVT (GT at FT – CVT) for (a) Speed 1, (c) Speed 2 and (e) Speed 3, also between the CVT and the GT at SUTB (CVT – GT at SUTB) for (b) Speed 1, (d) Speed 2 and (f) Speed 3.

Table 4.2: Power levels below which the CVT was more fuel efficient than the GT at FT and above which the GT at SUTB was more fuel efficient than the CVT.

	Average forward travel speed from CVT fuel efficiency test ($km \cdot h^{-1}$)	Maximum drawbar power of JD 8295R PST from official OECD test (kW)	Highest power level at which fuel consumption for CVT < for GT at FT (kW)	Percent of maximum power at selected speed (%)	Lowest power level at which fuel consumption for GT at SUTB < for CVT (kW)	Percent of maximum power at selected speed (%)
Speed 1	5.81	158.10	128	81.0	82	51.9
Speed 2	7.88	165.58	131	79.1	66.5	40.2
Speed 3	10.47	163.26	124	75.9	60	36.7
Average	-	-	127.7	78.7	69.5	42.9

The percent of maximum drawbar power at which a significant difference existed between transmission operating modes was plotted as a function of the average travel speed for each set point speed. As shown in Figure 4.4, there was a linearly decreasing trend for both the percent of maximum drawbar power below which the CVT was found to be more fuel efficient than the GT at FT and the percent of maximum drawbar power above which the GT at SUTB was found to be more fuel efficient than the CVT. Therefore, as speed increased, the percent of maximum power below which the CVT was significantly more fuel efficient than the GT at FT decreased slightly. Likewise, the percent of maximum power above which the GT at SUTB was more fuel efficient than the CVT decreased as speed increased. Knowing that travel speed has an impact on the fuel consumption of a tractor, it would be beneficial to test multiple speeds that cover the range of most drawbar applications during future testing. That way a trend line can be fitted to the data and a comparison can be made at any speed within the range fitted.

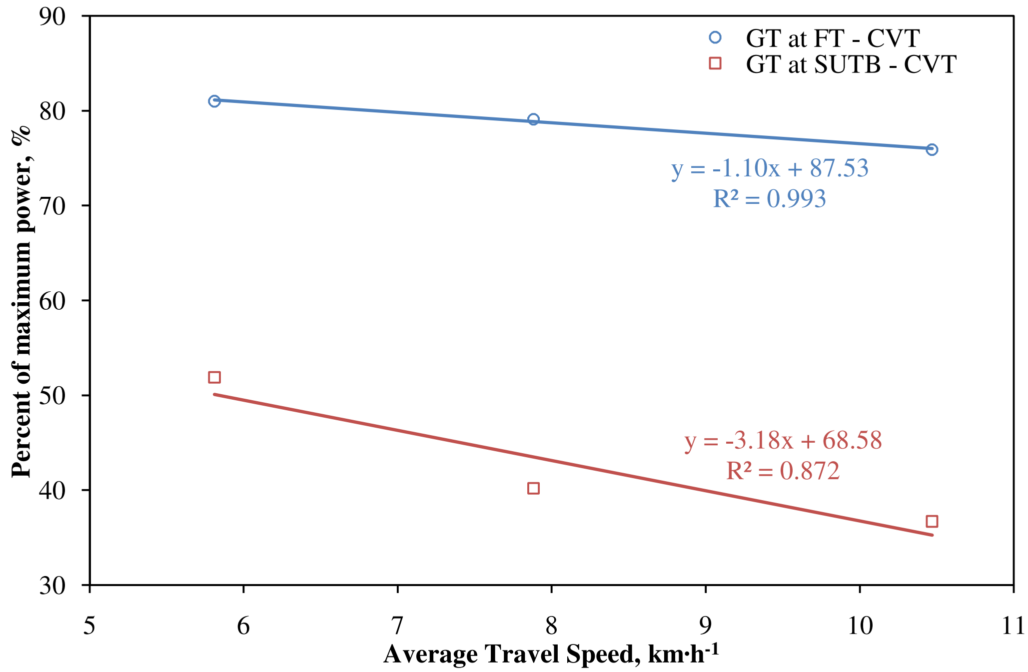

Figure 4.4: Percent of maximum drawbar power at which a significant difference existed between the two transmissions as a function of average travel speed for each speed set point.

Results from the analysis of the differences between predicted fuel consumption values at the different speed levels are shown in Figure 4.5. A comparison of the values of the predicted fuel consumption difference between Speed 1 and Speed 2 ($\hat{Q}$ for Speed 2 minus $\hat{Q}$ for Speed 1) with the 95% confidence interval for this difference showed that operating at Speed 1 produced significantly lower fuel consumption values for certain power ranges with certain transmission modes (Figure 4.5a, c and e). For the GT at FT, it was found that operating at Speed 1 produced significantly lower values below 93 kW (125 hp). For the GT at SUTB, there was no significant difference between Speeds 1 and 2. For the CVT, it was found that operating at Speed 1 produced significantly lower fuel consumption values between 58 kW (78 hp) and 85 kW (114 hp).

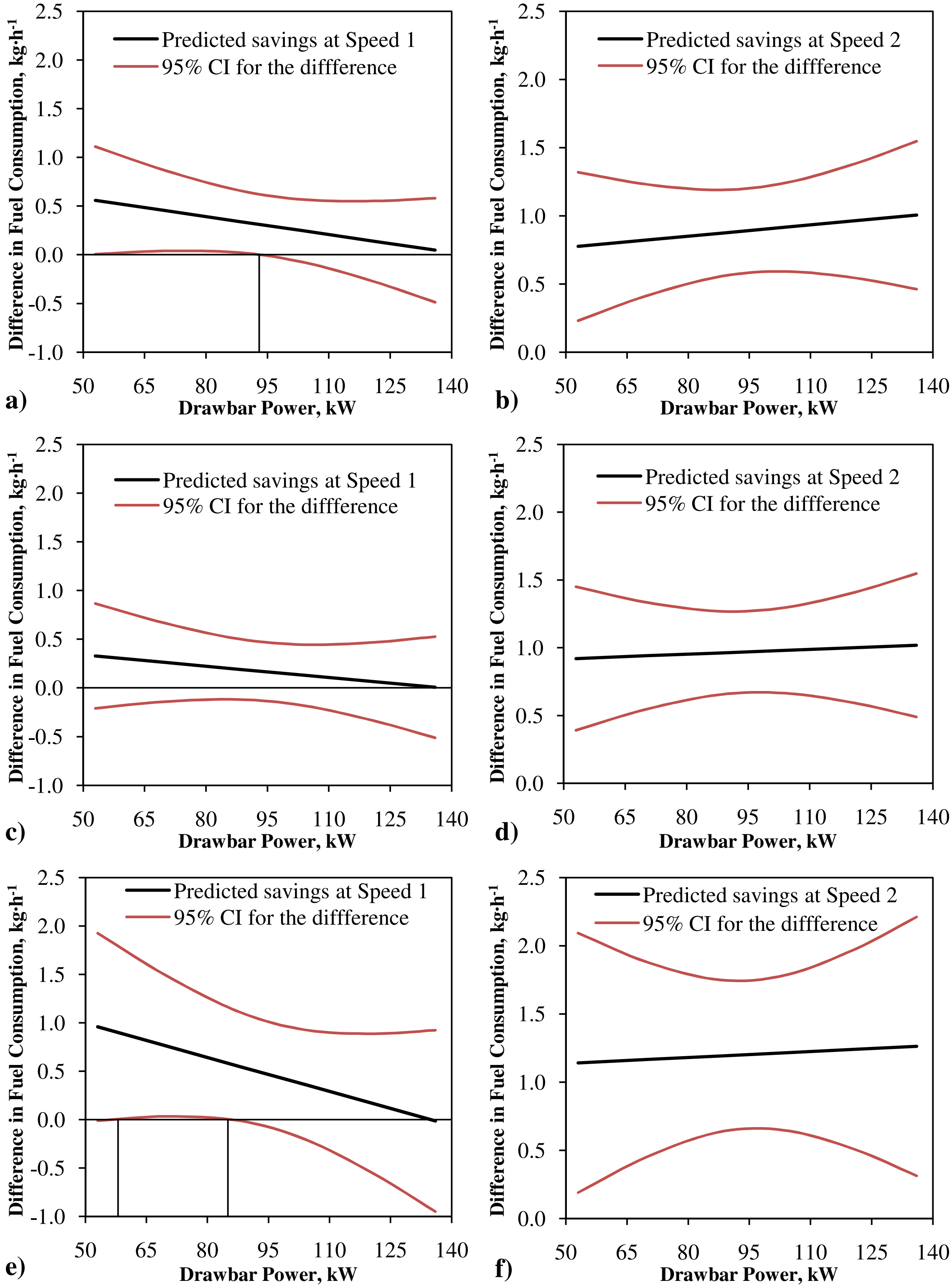

Figure 4.5. Difference in hourly predicted fuel consumption response to drawbar power between Speeds 1 and 2 (Speed 2 – Speed 1) for (a) GT at FT, (c) GT at SUTB and (e) CVT, also between Speeds 2 and 3 (Speed 3 – Speed 2) for (b) GT at FT, (d) GT at SUTB and (f) CVT.

A comparison of the values of the predicted fuel consumption difference between Speed 2 and Speed 3 ($\hat{Q}$ for Speed 3 minus $\hat{Q}$ for Speed 2) with the 95% confidence interval for this difference showed that operating at Speed 2 produced significantly lower hourly fuel consumption values for all three transmission modes (Figure 4.5b, d and f). Since a significant difference was found between Speeds 2 and 3, no analysis was performed between Speeds 1 and 3 because Speed 1 was guaranteed to produce significantly lower fuel consumption values than Speed 3.

The average difference between Speed 3 and Speed 2 was 2.59 $km \cdot h^{-1}$ (1.61 mph), while the average difference between Speed 2 and Speed 1 was 2.07 $km \cdot h^{-1}$ (1.29 mph). The smaller difference between Speeds 1 and 2 may be the reason that the predicted fuel consumption values were not all significantly different. Even though the predicted fuel consumption values for Speeds 1 and 2 were not always significantly different, this analysis still shows that there are differences in fuel consumption based on travel speed and that multiple speeds should be tested to determine predicted fuel consumption values for different field applications.

In an effort to gain a deeper understanding of why the transmission operating modes differ where they do, an investigation was carried out on the engine speed of the tractors in relationship to drawbar load, as shown in Figure 4.6. The engine speeds as a function of drawbar power for the GT at FT and the GT at SUTB seem parallel as did the fuel consumption lines. However, there were noticeable differences between the GT at FT and the CVT as well as between the GT at SUTB and the CVT. The differences between the engine speeds at the point where the two transmissions were found to produce significantly different fuel consumption results are marked by vertical lines and these differences are tabulated in Table 4.3.

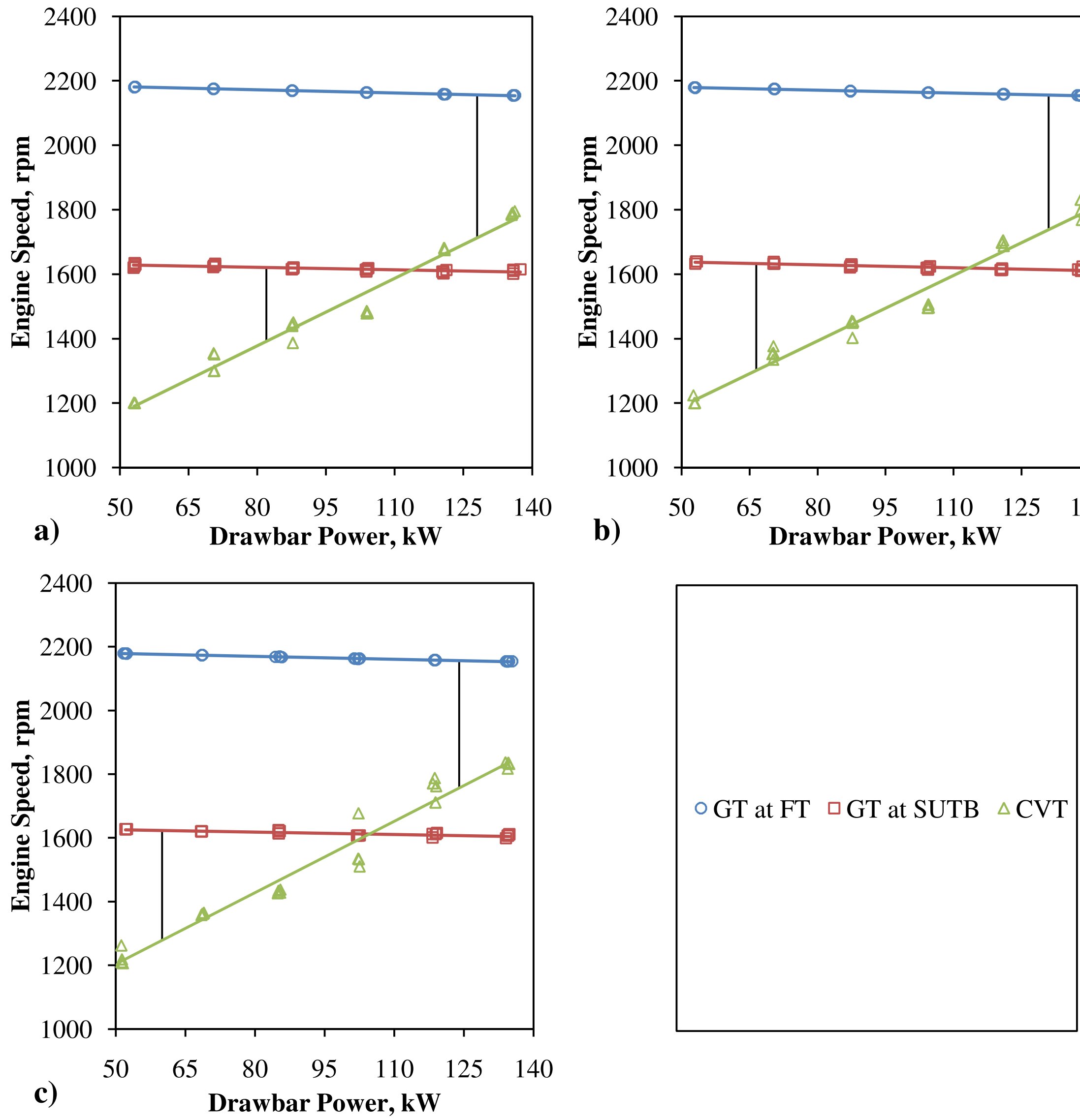

Figure 4.6: Engine speed as a function of drawbar power for all three transmission modes at (a) Speed 1, (b) Speed 2 and (c) Speed 3. The differences between predicted engine speeds at the points where the two transmissions produce significantly different fuel consumption values are marked with vertical lines.

As shown in Table 4.3, the minimum difference (GT at FT – CVT) in engine speed at which fuel consumption for the CVT became significantly less than for the GT at FT decreased as travel speed increased. Conversely, the maximum difference (GT at

SUTB – CVT) in engine speed below which fuel consumption for the GT at SUTB was significantly less than for the CVT increased as travel speed increased. In general, the CVT equipped tractor must reduce its engine speed roughly 400 rpm to 450 rpm below that of the GT equipped tractor when operating at the same power level before any significant fuel savings occurs. On the other hand, the GT equipped tractor operating under SUTB conditions was more fuel efficient than the CVT equipped tractor as long as its engine was turning less than 230 rpm to 340 rpm greater than that of the CVT equipped tractor operating at the same power level. These results show that to compensate for the parasitic losses associated with the CVT, the engine must turn at a significantly lower speed than that of the GT equipped tractor to make up the difference in fuel consumption.

Table 4.3: Differences in engine speeds when the fuel consumption became significantly different between the two transmission types.

Speed Designation	Average travel speed ($km \cdot h^{-1}$)	Minimum difference in engine speed at which fuel consumption for CVT < for GT at FT (GT at FT – CVT) (rpm)	Maximum difference in engine speed at which fuel consumption for GT at SUTB < for CVT (GT at SUTB – CVT) (rpm)
Speed 1	5.81	440	230
Speed 2	7.88	415	330
Speed 3	10.47	395	340
Average	-	417	300

Hourly fuel consumption predictions from the prediction equation for Speed 2 (approximately 7.9 $km \cdot h^{-1}$ (4.9 mph), 8^{th} gear for GT at FT, 10^{th} gear for GT at SUTB) compared with the results of the fuel consumption characteristics section of the OECD Code 2 test for the JD 8295R PST (NTTL, 2010) (approximately 7.8 $km \cdot h^{-1}$ (4.8 mph), 8th gear for maximum power, 11th gear for reduced engine speed) are shown in Table 4.4. The fuel consumption values at full engine speed compared very closely to the predicted values from the GT at FT. The fuel consumption values at reduced engine speed were all lower than the predicted values for the GT at SUTB and the CVT. Code 2 reduced engine speed in 11th gear saved about 6% more fuel than the GT at SUTB, and 11% to 12% more fuel than the CVT. It should be noted that the ballast configurations were different for the two tests, although, there was low enough wheel slip that this shouldn't affect the comparison significantly.

Table 4.4: Fuel consumption characteristics from official OECD Code 2 (unballasted) test (NTTL, 2010) of John Deere 8295R PST compared to predicted fuel consumption values from the CVT fuel efficiency (ballasted) test.

OECD Code 2 fuel consumption drawbar performance (unballasted)				CVT Fuel efficiency test (ballasted)		
Power level	Power (kW)	Travel speed ($km \cdot h^{-1}$)	Fuel consumption ($kg \cdot h^{-1}$)	Transmission mode used for fuel consumption prediction	Fuel consumption prediction from CVT fuel efficiency test ($kg \cdot h^{-1}$)	Percent difference of predicted fuel consumption compared to Code 2 fuel consumption (%)
Max power	165.58	7.45	42.2	GT at FT	43.2	2.34
75% of pull at max power	129.21	7.76	35.8	GT at FT	35.7	-0.18
50% of pull at max power	87.40	7.85	28.2	GT at FT	27.2	-3.59
75% of pull at max power with reduced engine speed	129.51	7.81	31.0	GT at SUTB	33.0	6.36
				CVT	35.1	12.39
50% of pull at max power with reduced engine speed	87.72	7.93	22.5	GT at SUTB	24.1	6.67
				CVT	25.1	10.95

A GT tractor operated in SUTB mode is capable of operating more efficiently than a CVT tractor at steady state loads. However, during realistic field conditions, the soil conditions will vary causing the drawbar load to vary dynamically through the field.

The operator of a GT tractor would have to constantly watch the fuel use display and adjust the throttle and gear settings to maintain a constant speed through the field, whereas the CVT tractor has the benefit of automatically being able to shift the transmission into the proper ratio and adjust the engine speed based on the varying load. The CVT tractor also has the additional benefits of being able to operate at any speed within its operating range and has a built in active load control system. The CVT controller will automatically shift down and throttle the engine up to prevent damage being done to the tractor. However, if the GT tractor is equipped with some sort of cruise control or an automatic shift system with throttle control, then that could effectively do the same job as the controller on the CVT tractor.

It should also be mentioned that the speeds selected for testing were possibly biased. In other words, the speeds selected corresponded to the maximum speed of particular gear ratios for the GT tractor. Had other speeds been chosen that required different throttle settings to achieve, the CVT might have tested better as it is capable of operating at any gear ratio. However, the idea behind a CVT is that it is capable of operating efficiently at any gear ratio within its operational range, and the speeds tested were required in order to be able to achieve a comparison with the GT at FT.

4.3 Future Work

Additional testing is needed on other models of tractors from other manufacturers to determine whether the trends found in this study pertain to all CVT equipped tractors or if they are specific to this tractor model and manufacturer. It might also be worthwhile to test at alternate speeds to determine whether the trends found in this study still apply.

5 Conclusions

The results indicated that the CVT operated in automatic mode was more fuel efficient than the standard geared transmission operated at full engine speed when the drawbar power was less than 76% to 81% of maximum drawbar power. This was expected since the CVT automatically shifted up and throttled back to achieve the same travel speed at a lower engine speed. These results also correlated almost exactly with the results that Coffman et al. (2010) achieved with testing on the JD 8530 IVT. The results also indicated, however, that the same geared transmission operated at a reduced engine speed and shifted up two gears achieved greater fuel efficiency than the CVT when the drawbar power was greater than 37% to 52% of maximum drawbar power. This makes sense, though, since there are inherently higher parasitic losses associated with a CVT than with a standard geared transmission.

The point at which the fuel consumption was found to be significantly different between transmissions when correlated to the forward travel speed was also determined. As travel speed increased, the percent of maximum power below which the CVT was significantly more fuel efficient than the GT at FT decreased. Likewise, the percent of maximum power above which the GT at SUTB was more fuel efficient than the CVT decreased as speed increased. This suggests that multiple speeds need to be tested to achieve an accurate comparison between a GT and a CVT. The minimum number required would be two that span the range of working speeds that the tractor is used for, although testing at least three speeds would be recommended.

The relationship between fuel consumption and drawbar power was found to be linear. Therefore, the minimum number of load levels that need to be tested for each travel speed is three loads that span the entire range to obtain a minimal evaluation of how well the linear model fit the data. However, it is recommended that more than three load levels are tested to achieve a reasonable estimate of how well the linear model fit the data.

Limitations to the study existed. Only one model of tractor was tested from one manufacturer, which does not give any information on how other models or tractors from other manufacturers would perform. Also, the test speeds were chosen based off of the maximum speeds in certain gears for the GT tractor and it is possible that different results may have been achieved if other speeds had been chosen.

6 Proposed Optional CVT Fuel Consumption at Varying Drawbar Loads Test Procedure

The following test procedure is recommended by author for insertion as Section 4.4.8 in OECD Code 2 under the heading: "CVT fuel consumption at varying drawbar loads." Also, this test is to comply with all existing requirements for drawbar testing such as ambient conditions, test track, instrumentation, etc., as specified in OECD Code 2 (OECD, 2010)

6.1 Test Procedure

This test is designed especially to compare the fuel efficiency of tractor models that are available with the option to have either a standard geared transmission (GT) installed or a CVT installed. In order to do that both a tractor equipped with a GT and a tractor equipped with a CVT must both be tested. Since there are two basic ways of operating a geared transmission tractor, full throttle (FT) or shifted-up and throttled-back (SUTB), there are three different tests that shall be performed. The first should involve the geared transmission operating at full throttle, the second should involve the geared transmission operating under shift-up-throttle-back conditions, and the third should involve the CVT. With this in mind the following requirements were developed.

6.1.1 Speed/Gear Selection

A minimum of three speeds/gears must be tested within the range of 5 $km \cdot h^{-1}$ (3 mph) to 11 $km \cdot h^{-1}$ (7 mph). The three test speeds should be based off of the speed achieved with the tractor equipped with the geared transmission with the throttle set to maximum. The GT at SUTB conditions can be set to any speed by adjusting the throttle and the CVT can also be set to any speed. The number of gears shifted up may be determined by the manufacturer in accordance with the test station and should correspond to the maximum fuel efficiency achievable by the tractor for the given speed and loading. The number of gears shifted up should remain constant for all three speeds tested.

6.1.2 Drawbar Loading

Six drawbar loads should be tested for each speed and should correspond to 30%, 40%, 50%, 60%, 70% and 80% of the load achieved at maximum power by the GT tractor at FT for each individual speed as determined during the unballasted portion of the official testing. Steady state operating conditions must have been attained at each load setting before taking measurements as mentioned in Section 3.4.4 of OECD Code 2 and measurements must be taken over a distance of at least 20 m (66 ft) as specified in Section 2.5 of OECD Code 2.

6.1.3 Ballasting

The amount and placement of ballast weights fitted to the tractor may be decided by the manufacturer, but must not exceed the limits specified by the manufacturer. Also, the pressure in the tires must fall within the limits specified by the manufacturer for the given ballast configuration.

6.2 Graphical Presentation of Results

Hourly fuel consumption values for all three tests should be plotted against drawbar power for each tractor. All of the lines from a single speed tested may be shown on the same graph, but a separate graph needs to be generated for each speed tested. The equations for the best fit lines should be shown for each transmission mode so that comparisons can be made.

7 References

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Appendix A: Excerpt from JD 8295R Operator Manual Detailing IVT Options

IVT (Infinitely Variable Transmission)™ Selector Guidelines and Examples

NOTE: For most applications, maximum productivity and fuel economy is realized when modes 1, 2 or 3 are selected.

Minimum engine speed values of modes 1, 2, or 3 are adjustable. See Setting IVT Options in this section.

IVT has four modes providing two automated productivity functions:

- **Load control** provides automatic transmission ground speed adjustment under load to maintain constant peak power levels and maximum productivity.
- **Fuel economy** function provides constant vehicle speed at reduced engine speed in light load or no-load conditions.

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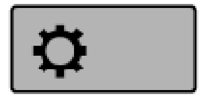

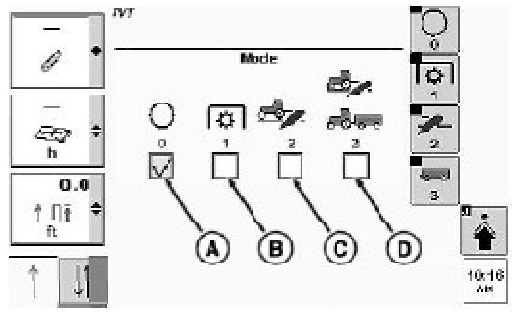

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A—OFF
B—PTO Mode
C—Auto Mode 2—Heavy Tillage
D—Auto Mode 3—Transport or Light Tillage

VT Modes		
A-OFF	Transmission will not shift automatically to maintain engine rpm with varying loads	• Use OFF position if application is causing undesired automatic shifting. • Use OFF position when operating on steep and/or slippery downhill slopes. (See Downhill Operation in Slippery Conditions in this section.) • Load control function OFF • Fuel economy function OFF
B-Auto Mode 1	Most PTO and High Hydraulic flow Applications	• Load control function ON * • Fuel economy function OFF • Using correct engine speed is very important for PTO operations. • Field Cruise may be used to limit engine speed. • Refer to implement Operator's Manual for specific implement speeds • Approximately 1800 engine rpm equals 540 PTO rpm • Approximately 2000 engine rpm equals 1000 PTO rpm
C-Auto Mode 2	Plowing and Tillage	• Use full throttle position • Adjust Auto 2 set speed to match application • Load control function ON * • Fuel economy function ON **
D-Auto Mode 3	Transport and Light Tillage	• Use full throttle position • Adjust Auto 3 set speed to match application • Load control function ON * • Fuel economy function ON **
* See Engine Speeds - IVT Options Auto With and Without PTO. ** See Auto Mode 2 and Auto Mode 3 fuel economy settings.		

IVT (Infinitely Variable Transmission) is a trademark of Deere & Company

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Downhill Operation In Slippery Conditions

CAUTION: Avoid possible injury from losing control of tractor while operating on a downhill slope. Tractor wheels may lock and skid on slippery downhill slopes. Observe the following precautions:

- **Adjust set speed value to a safe downhill operating speed.**
- **Place IVT (Infinitely Variable Transmission)™ selector in OFF position (A). (The higher brake pedal force required in the OFF position will help prevent wheel lock and skidding.)**
- **Do not make major speed reductions with the speed control lever.**

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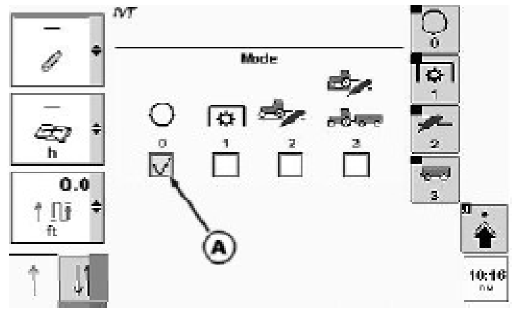

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A—OFF Position

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Setting IVT (Infinitely Variable Transmission)™ Options

A Load Anticipation feature allows IVT to predict how much "hydraulic load" engine expects from activation of hitch or a particular SCV function. For this to be activated, SCV or hitch lever is placed in **detented position** when "hydraulic load" is decreasing. IVT remembers that load change. When it detects the **same lever starting movement in the opposite direction**, it responds with a short engine rpm boost thus providing more power to better handle on-coming load increase.

For engine rpm see Load Control Function—Engine RPM Droop IVT Options (Modes 1, 2, and 3) Auto With and Without PTO.

Load Control Function Settings

1. Select **Transmission**.
2. Select **Advanced Setting soft key.**
3. When IVT Settings page appears, select drop down box (A) to change AUTO with PTO setting.

NOTE: When selection is made in pull down menu, display in IVT Settings Page will update automatically.

4. Make selection of options displayed. For this example; select LOW (C).
5. Using drop down box (B), follow above procedure to select setting AUTO—no PTO.
6. Drop down box will offer same options described above and for this example; select MED/HIGH (D).

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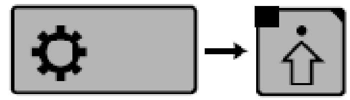
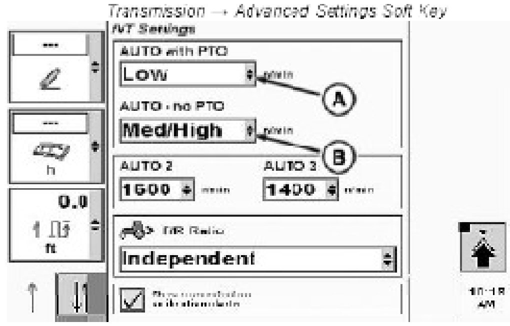


Transmission → Advanced Settings Soft Key



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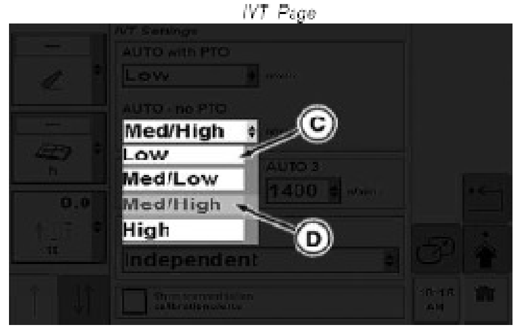
IVT Page



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Drop Down Box

A—Drop Down Box—AUTO with PTO
B—Drop Down Box—AUTO no PTO
C—Selection—Low
D—Selection—Med/High

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Continued on next page

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Fuel Economy Function Settings

Both AUTO mode 2 and AUTO mode 3 are fuel economy settings. Auto mode 2 is used to adjust minimum engine speed when operating with a light load. See **Auto Mode 2 Options** table for a list of selections to choose from. The default engine rpm setting in AUTO mode 2 is 1500 rpm.

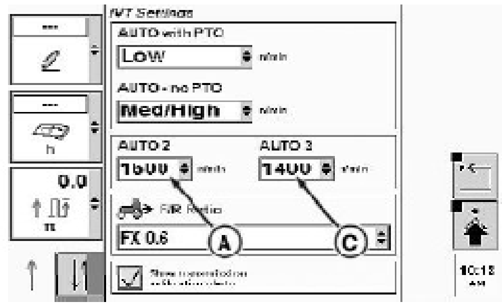
IVT Options	Auto Mode 2	1500 rpm
		1600 rpm
		1700 rpm
		1800 rpm

AUTO Mode 3 is much the same as Auto Mode 2. See **Auto Mode 3 Options** table for a list of selections to choose from. The default engine rpm setting in AUTO Mode 3 is 1200 rpm.

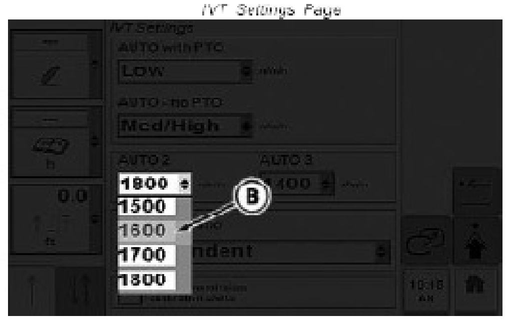
IVT Options	Auto 3	1200 rpm
		1300 rpm
		1400 rpm
		1500 rpm

1. Select Auto Mode 2 engine rpm setting (A)
2. When drop down box appears, select desired setting. For this example, select 1600 (B) which will display in IVT Settings screen for Auto Mode 2 rpm rate.
3. Select Auto Mode 3 engine rpm settings (C).
4. When drop down box appears, select desired setting. For this example, select 1400 (B) which will display in IVT Settings screen for AUTO Mode 3 rpm rate.

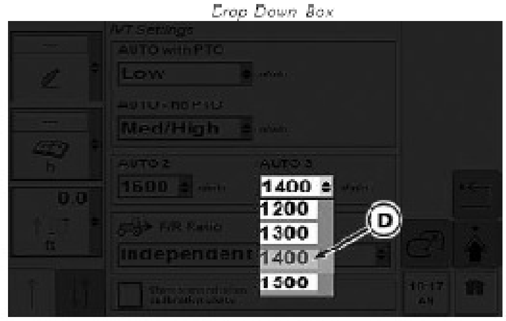
A—Auto Mode 2
B—Selection for Auto Mode 2
C—AUTO Mode 3
D—Selection for AUTO Mode 3



IVT Settings Page



Drop Down Box



Drop Down Box

Appendix B: SAS Code and Output

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 1. In the following program, M represents the transmission mode (GT at FT = 1, GT at SUTB = 2, CVT = 3), P represents drawbar power (kW) and Q represents fuel consumption ($kg \cdot h^{-1}$).

```
DATA GTFT;
INPUT M P Q;
CARDS;
1      136.3 36.7
1      136.0 36.8
1      136.0 37.0
1      135.8 36.8
1      121.2 34.2
1      120.7 33.8
1      120.6 33.9
1      120.8 34.1
1      103.8 30.5
1      103.8 30.3
1      104.0 30.3
1      103.8 30.3
1      87.7  26.9
1      87.5  26.3
1      87.7  26.3
1      87.6  26.3
1      70.3  23.7
1      70.5  23.4
1      70.5  23.1
1      70.5  22.9
1      53.1  20.7
1      53.3  19.5
1      53.3  19.4
1      53.4  19.3
2      135.9 34.5
2      137.4 35.1
2      135.9 34.7
2      135.9 34.8
2      120.6 30.7
2      120.4 30.7
2      120.6 30.8
2      121.3 31.0
2      103.7 27.3
2      104.0 27.2
2      103.8 27.1
2      104.2 27.3
2      87.9  24.3
2      87.9  24.1
2      87.8  23.8
2      87.5  24.0
2      70.6  19.9
2      70.8  19.7
2      70.4  19.9
2      70.8  19.7
2      53.0  15.8
```

```
2       53.2  16.0
2       53.2  18.4
2       53.4  16.0
3       135.5 36.8
3       135.6 36.9
3       135.8 36.9
3       136.2 37.6
3       120.8 33.0
3       120.9 33.0
3       120.9 33.4
3       120.9 33.2
3       103.9 27.6
3       104.1 27.7
3       104.0 27.6
3       103.9 27.6
3       87.6  23.6
3       87.6  23.8
3       87.8  23.2
3       87.9  24.0
3       70.5  20.7
3       70.6  21.2
3       70.5  21.2
3       70.6  20.7
3       53.2  16.2
3       53.3  16.2
3       53.1  16.0
3       53.1  16.0
;

PROC PRINT DATA=GTFT;
RUN;

PROC GLM DATA=GTFT;
  CLASS M;
  MODEL Q=P|M/SOLUTION;
RUN;

PROC MIXED DATA=GTFT;
  CLASS M;
  MODEL Q=P|M/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS m/ AT p=53 diff CL alpha=0.0083;
   LSMEANS m/ AT p=70 diff CL alpha=0.0083;
   LSMEANS m/ AT p=88 diff CL alpha=0.0083;
   LSMEANS m/ AT p=104 diff CL alpha=0.0083;
   LSMEANS m/ AT p=121 diff CL alpha=0.0083;
   LSMEANS m/ AT p=136 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 1. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3081.831536	616.366307	1929.08	<.0001
Error	66	21.087908	0.319514		
Corrected Total	71	3102.919444			

R-Square	Coeff Var	Root MSE	Q Mean
0.993204	2.109381	0.565255	26.79722

The Mixed Procedure

Solution for Fixed Effects

Effect	M	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		2.5648	0.4052	66	6.33	<.0001
P		0.2502	0.004074	66	61.41	<.0001
M	1	5.9273	0.5727	66	10.35	<.0001
M	2	2.0955	0.5726	66	3.66	0.0005
M	3	0	.	.	.	.
P*M	1	-0.04101	0.005758	66	-7.12	<.0001
P*M	2	-0.03147	0.005754	66	-5.47	<.0001
P*M	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	9253.47	<.0001
M	2	66	168.19	<.0001
P*M	2	66	27.77	<.0001

The Mixed Procedure

Differences of Least Squares Means

Effect	M	_M	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
M	1	2	53.00	3.3263	0.2933	66	11.34	<.0001	0.0083	2.5280	4.1245
M	1	3	53.00	3.7540	0.2934	66	12.80	<.0001	0.0083	2.9555	4.5524
M	2	3	53.00	0.4277	0.2935	66	1.46	0.1497	0.0083	-0.3710	1.2264
M	1	2	70.00	3.1641	0.2189	66	14.45	<.0001	0.0083	2.5683	3.7600
M	1	3	70.00	3.0569	0.2189	66	13.96	<.0001	0.0083	2.4611	3.6526
M	2	3	70.00	-0.1073	0.2190	66	-0.49	0.6260	0.0083	-0.7033	0.4888
M	1	2	88.00	2.9924	0.1686	66	17.75	<.0001	0.0083	2.5335	3.4513
M	1	3	88.00	2.3188	0.1686	66	13.76	<.0001	0.0083	1.8600	2.7775
M	2	3	88.00	-0.6737	0.1686	66	-4.00	0.0002	0.0083	-1.1326	-0.2148
M	1	2	104.00	2.8398	0.1705	66	16.65	<.0001	0.0083	2.3757	3.3039
M	1	3	104.00	1.6627	0.1706	66	9.74	<.0001	0.0083	1.1983	2.1270
M	2	3	104.00	-1.1771	0.1705	66	-6.90	<.0001	0.0083	-1.6413	-0.7130
M	1	2	121.00	2.6776	0.2198	66	12.18	<.0001	0.0083	2.0794	3.2759
M	1	3	121.00	0.9656	0.2201	66	4.39	<.0001	0.0083	0.3665	1.5646
M	2	3	121.00	-1.7121	0.2199	66	-7.79	<.0001	0.0083	-2.3105	-1.1136
M	1	2	136.00	2.5346	0.2849	66	8.90	<.0001	0.0083	1.7591	3.3100
M	1	3	136.00	0.3505	0.2853	66	1.23	0.2237	0.0083	-0.4261	1.1271
M	2	3	136.00	-2.1841	0.2850	66	-7.66	<.0001	0.0083	-2.9599	-1.4083

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 2. In the following program, M represents the transmission mode (GT at FT = 1, GT at SUTB = 2, CVT = 3), P represents drawbar power (kW) and Q represents fuel consumption ($kg \cdot h^{-1}$).

```
DATA GTSUTB;
INPUT M P Q;
CARDS;
1      137.4 36.9
1      138.0 36.9
1      138.2 37.6
1      137.9 37.2
1      121.2 34.1
1      120.9 34.2
1      120.9 34.2
1      121.0 34.2
1      104.3 30.9
1      104.3 30.9
1      104.6 30.6
1      104.4 30.7
1      87.3  28.3
1      87.2  26.4
1      87.3  26.8
1      87.2  26.7
1      70.3  23.4
1      70.6  23.4
1      70.5  23.4
1      70.5  23.2
1      53.0  21.3
1      52.7  20.0
1      53.1  20.1
1      53.1  19.8
2      137.5 34.7
2      138.1 34.8
2      138.4 35.0
2      138.5 35.1
2      120.4 30.9
2      120.7 31.1
2      120.6 30.8
2      120.7 30.8
2      104.8 27.9
2      104.3 27.7
2      104.1 27.5
2      104.4 27.5
2      87.5  24.5
2      87.2  24.1
2      87.5  24.2
2      87.2  24.2
2      70.3  20.4
2      70.5  20.6
2      70.4  20.2
2      70.3  20.1
2      53.0  16.5
```

```
2       53.2  16.5
2       53.3  16.5
2       53.3  16.4
3       138.1 37.7
3       138.1 37.3
3       138.9 37.7
3       138.4 37.3
3       121.0 33.3
3       120.7 33.2
3       120.8 33.2
3       121.1 33.3
3       104.5 28.4
3       104.6 28.5
3       104.3 28.4
3       104.5 28.2
3       87.6  24.3
3       87.7  24.1
3       87.9  24.4
3       87.7  24.2
3       70.3  22.1
3       70.0  21.8
3       70.2  21.7
3       70.3  21.4
3       52.9  16.7
3       53.0  16.7
3       52.8  16.9
3       52.6  16.7
;

PROC PRINT DATA=GTSUTB;
RUN;

PROC GLM DATA=GTSUTB;
  CLASS M;
  MODEL Q=P|M/SOLUTION;
RUN;

PROC MIXED DATA=GTSUTB;
  CLASS M;
  MODEL Q=P|M/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS m/ AT p=53 diff CL alpha=0.0083;
   LSMEANS m/ AT p=70 diff CL alpha=0.0083;
   LSMEANS m/ AT p=87 diff CL alpha=0.0083;
   LSMEANS m/ AT p=104 diff CL alpha=0.0083;
   LSMEANS m/ AT p=121 diff CL alpha=0.0083;
   LSMEANS m/ AT p=138 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 2. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3025.141999	605.028400	2689.40	<.0001
Error	66	14.847862	0.224968		
Corrected Total	71	3039.989861			

R-Square	Coeff Var	Root MSE	Q Mean
0.995116	1.745293	0.474308	27.17639

The Mixed Procedure

Solution for Fixed Effects

Effect	M	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		4.1412	0.3328	66	12.44	<.0001
P		0.2385	0.003326	66	71.72	<.0001
M	1	5.2358	0.4717	66	11.10	<.0001
M	2	1.0512	0.4721	66	2.23	0.0294
M	3	0	.	.	.	.
P*M	1	-0.03548	0.004717	66	-7.52	<.0001
P*M	2	-0.02365	0.004720	66	-5.01	<.0001
P*M	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	12884.2	<.0001
M	2	66	252.05	<.0001
P*M	2	66	29.37	<.0001

The Mixed Procedure

Differences of Least Squares Means

Effect	M	_M	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
M	1	2	53.00	3.5574	0.2440	66	14.58	<.0001	0.0083	2.8934	4.2215
M	1	3	53.00	3.3553	0.2436	66	13.78	<.0001	0.0083	2.6925	4.0182
M	2	3	53.00	-0.2021	0.2437	66	-0.83	0.4099	0.0083	-0.8653	0.4612
M	1	2	70.00	3.3563	0.1831	66	18.33	<.0001	0.0083	2.8581	3.8545
M	1	3	70.00	2.7522	0.1829	66	15.05	<.0001	0.0083	2.2545	3.2499
M	2	3	70.00	-0.6041	0.1830	66	-3.30	0.0016	0.0083	-1.1021	-0.1062
M	1	2	87.00	3.1552	0.1429	66	22.07	<.0001	0.0083	2.7662	3.5442
M	1	3	87.00	2.1490	0.1429	66	15.03	<.0001	0.0083	1.7600	2.5381
M	2	3	87.00	-1.0061	0.1430	66	-7.04	<.0001	0.0083	-1.3952	-0.6170
M	1	2	104.00	2.9540	0.1425	66	20.73	<.0001	0.0083	2.5663	3.3418
M	1	3	104.00	1.5459	0.1424	66	10.86	<.0001	0.0083	1.1583	1.9334
M	2	3	104.00	-1.4081	0.1424	66	-9.89	<.0001	0.0083	-1.7957	-1.0206
M	1	2	121.00	2.7529	0.1820	66	15.13	<.0001	0.0083	2.2576	3.2482
M	1	3	121.00	0.9427	0.1816	66	5.19	<.0001	0.0083	0.4485	1.4370
M	2	3	121.00	-1.8102	0.1816	66	-9.97	<.0001	0.0083	-2.3045	-1.3158
M	1	2	138.00	2.5518	0.2427	66	10.51	<.0001	0.0083	1.8913	3.2123
M	1	3	138.00	0.3396	0.2419	66	1.40	0.1651	0.0083	-0.3189	0.9981
M	2	3	138.00	-2.2122	0.2420	66	-9.14	<.0001	0.0083	-2.8709	-1.5534

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 3. In the following program, M represents the transmission mode (GT at FT= 1, GT at SUTB = 2, CVT = 3), P represents drawbar power (kW) and Q represents fuel consumption ($kg{\cdot}h^{-1}$).

```
DATA CVT;
INPUT M P Q;
CARDS;
1      134.4 37.6
1      134.8 37.4
1      135.4 37.4
1      134.1 37.4
1      118.9 34.7
1      118.9 34.5
1      118.7 34.5
1      118.6 34.4
1      102.3 31.5
1      101.6 31.3
1      102.5 31.3
1      101.4 31.3
1      85.8  28.2
1      85.4  27.5
1      84.4  27.3
1      85.2  27.4
1      68.7  24.2
1      68.5  24.2
1      68.5  23.9
1      68.5  23.5
1      52.3  21.1
1      51.6  20.4
1      52.3  20.5
1      51.9  20.6
2      134.8 35.6
2      134.5 35.2
2      134.1 35.4
2      134.4 34.8
2      118.2 31.0
2      118.2 31.7
2      119.2 31.6
2      118.9 31.5
2      102.0 28.2
2      102.6 28.0
2      102.3 27.9
2      102.1 27.7
2      85.1  25.1
2      85.3  24.7
2      85.1  24.6
2      85.1  24.9
2      68.4  21.0
2      68.5  20.7
2      68.4  20.9
2      68.5  20.7
2      52.1  17.6
```

```
2       52.4  17.1
2       52.1  17.0
2       52.1  17.2
3       134.4 37.5
3       134.0 37.6
3       134.6 37.6
3       134.7 37.9
3       118.3 34.1
3       118.9 33.8
3       118.7 34.3
3       119.0 34.1
3       102.2 29.3
3       102.4 29.2
3       102.5 28.8
3       102.3 30.3
3       85.1  24.9
3       85.5  24.6
3       85.4  24.3
3       84.9  24.4
3       69.0  22.5
3       68.9  22.7
3       68.6  22.5
3       68.5  22.6
3       51.2  17.5
3       51.3  17.5
3       51.5  17.7
3       51.2  17.5
;

PROC PRINT DATA=CVT;
RUN;

PROC GLM DATA=CVT;
  CLASS M;
  MODEL Q=P|M/SOLUTION;
RUN;

PROC MIXED DATA=CVT;
  CLASS M;
  MODEL Q=P|M/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS m/ AT p=52 diff CL alpha=0.0083;
   LSMEANS m/ AT p=68 diff CL alpha=0.0083;
   LSMEANS m/ AT p=85 diff CL alpha=0.0083;
   LSMEANS m/ AT p=102 diff CL alpha=0.0083;
   LSMEANS m/ AT p=119 diff CL alpha=0.0083;
   LSMEANS m/ AT p=135 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for speed setting 3. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2936.360798	587.272160	2545.76	<.0001
Error	66	15.225313	0.230687		
Corrected Total	71	2951.586111			

R-Square	Coeff Var	Root MSE	Q Mean
0.994842	1.733060	0.480298	27.71389

The Mixed Procedure

Solution for Fixed Effects

Effect	M	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		5.2048	0.3368	66	15.45	<.0001
P		0.2400	0.003448	66	69.60	<.0001
M	1	4.8011	0.4773	66	10.06	<.0001
M	2	0.8455	0.4779	66	1.77	0.0815
M	3	0	.	.	.	.
P*M	1	-0.03417	0.004884	66	-7.00	<.0001
P*M	2	-0.02393	0.004892	66	-4.89	<.0001
P*M	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	12209.1	<.0001
M	2	66	234.05	<.0001
P*M	2	66	25.80	<.0001

The Mixed Procedure

Differences of Least Squares Means

Effect	M	_M	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
M	1	2	52.00	3.4228	0.2462	66	13.90	<.0001	0.0083	2.7528	4.0929
M	1	3	52.00	3.0241	0.2456	66	12.31	<.0001	0.0083	2.3557	3.6924
M	2	3	52.00	-0.3988	0.2458	66	-1.62	0.1095	0.0083	-1.0677	0.2702
M	1	2	68.00	3.2589	0.1867	66	17.45	<.0001	0.0083	2.7507	3.7671
M	1	3	68.00	2.4773	0.1864	66	13.29	<.0001	0.0083	1.9701	2.9845
M	2	3	68.00	-0.7816	0.1865	66	-4.19	<.0001	0.0083	-1.2891	-0.2741
M	1	2	85.00	3.0847	0.1448	66	21.30	<.0001	0.0083	2.6906	3.4788
M	1	3	85.00	1.8963	0.1447	66	13.10	<.0001	0.0083	1.5024	2.2902
M	2	3	85.00	-1.1884	0.1447	66	-8.21	<.0001	0.0083	-1.5823	-0.7945
M	1	2	102.00	2.9105	0.1447	66	20.11	<.0001	0.0083	2.5166	3.3044
M	1	3	102.00	1.3153	0.1447	66	9.09	<.0001	0.0083	0.9214	1.7093
M	2	3	102.00	-1.5952	0.1448	66	-11.02	<.0001	0.0083	-1.9891	-1.2012
M	1	2	119.00	2.7363	0.1866	66	14.67	<.0001	0.0083	2.2285	3.2441
M	1	3	119.00	0.7344	0.1864	66	3.94	0.0002	0.0083	0.2271	1.2417
M	2	3	119.00	-2.0019	0.1865	66	-10.73	<.0001	0.0083	-2.5096	-1.4943
M	1	2	135.00	2.5723	0.2460	66	10.46	<.0001	0.0083	1.9028	3.2419
M	1	3	135.00	0.1876	0.2456	66	0.76	0.4477	0.0083	-0.4808	0.8560
M	2	3	135.00	-2.3848	0.2459	66	-9.70	<.0001	0.0083	-3.0539	-1.7156

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the GT at FT. In the following program, S represents the travel speed (Speed 1 = 1, Speed 2 = 2, Speed 3 = 3), P represents drawbar power (kW) and Q represents fuel consumption (kg·h^{-1}).

```
DATA GTFT;
INPUT S P Q;
CARDS;
1      136.3 36.7
1      136.0 36.8
1      136.0 37.0
1      135.8 36.8
1      121.2 34.2
1      120.7 33.8
1      120.6 33.9
1      120.8 34.1
1      103.8 30.5
1      103.8 30.3
1      104.0 30.3
1      103.8 30.3
1      87.7  26.9
1      87.5  26.3
1      87.7  26.3
1      87.6  26.3
1      70.3  23.7
1      70.5  23.4
1      70.5  23.1
1      70.5  22.9
1      53.1  20.7
1      53.3  19.5
1      53.3  19.4
1      53.4  19.3
2      137.4 36.9
2      138.0 36.9
2      138.2 37.6
2      137.9 37.2
2      121.2 34.1
2      120.9 34.2
2      120.9 34.2
2      121.0 34.2
2      104.3 30.9
2      104.3 30.9
2      104.6 30.6
2      104.4 30.7
2      87.3  28.3
2      87.2  26.4
2      87.3  26.8
2      87.2  26.7
2      70.3  23.4
2      70.6  23.4
2      70.5  23.4
2      70.5  23.2
2      53.0  21.3
2      52.7  20.0
```

```
2       53.1  20.1
2       53.1  19.8
3       134.4 37.6
3       134.8 37.4
3       135.4 37.4
3       134.1 37.4
3       118.9 34.7
3       118.9 34.5
3       118.7 34.5
3       118.6 34.4
3       102.3 31.5
3       101.6 31.3
3       102.5 31.3
3       101.4 31.3
3       85.8  28.2
3       85.4  27.5
3       84.4  27.3
3       85.2  27.4
3       68.7  24.2
3       68.5  24.2
3       68.5  23.9
3       68.5  23.5
3       52.3  21.1
3       51.6  20.4
3       52.3  20.5
3       51.9  20.6
;

PROC PRINT DATA=GTFT;
RUN;

PROC GLM DATA=GTFT;
  CLASS S;
  MODEL Q=P|S/SOLUTION;
RUN;

PROC MIXED DATA=GTFT;
  CLASS S;
  MODEL Q=P|S/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS s/ AT p=53 diff CL alpha=0.0083;
   LSMEANS s/ AT p=70 diff CL alpha=0.0083;
   LSMEANS s/ AT p=88 diff CL alpha=0.0083;
   LSMEANS s/ AT p=104 diff CL alpha=0.0083;
   LSMEANS s/ AT p=121 diff CL alpha=0.0083;
   LSMEANS s/ AT p=136 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the GT at FT. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2498.118536	499.623707	3241.04	<.0001
Error	66	10.174242	0.154155		
Corrected Total	71	2508.292778			

R-Square	Coeff Var	Root MSE	Q Mean
0.995944	1.361840	0.392626	28.83056

The Mixed Procedure

Solution for Fixed Effects

Effect	S	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		10.0059	0.2764	66	36.20	<.0001
P		0.2058	0.002828	66	72.77	<.0001
S	1	-1.5138	0.3942	66	-3.84	0.0003
S	2	-0.6289	0.3911	66	-1.61	0.1126
S	3	0	.	.	.	.
P*S	1	0.003400	0.003998	66	0.85	0.3982
P*S	2	-0.00276	0.003958	66	-0.70	0.4876
P*S	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	16083.4	<.0001
S	2	66	59.69	<.0001
P*S	2	66	1.22	0.3030

Differences of Least Squares Means

Effect	S	_S	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
S	1	2	53.00	-0.5583	0.2028	66	-2.75	0.0076	0.0083	-1.1101	-0.00644
S	1	3	53.00	-1.3336	0.2008	66	-6.64	<.0001	0.0083	-1.8800	-0.7872
S	2	3	53.00	-0.7753	0.1998	66	-3.88	0.0002	0.0083	-1.3192	-0.2314
S	1	2	70.00	-0.4535	0.1517	66	-2.99	0.0039	0.0083	-0.8665	-0.04057
S	1	3	70.00	-1.2758	0.1497	66	-8.52	<.0001	0.0083	-1.6832	-0.8685
S	2	3	70.00	-0.8223	0.1494	66	-5.50	<.0001	0.0083	-1.2289	-0.4157
S	1	2	88.00	-0.3426	0.1172	66	-2.92	0.0047	0.0083	-0.6615	-0.02374
S	1	3	88.00	-1.2146	0.1163	66	-10.45	<.0001	0.0083	-1.5311	-0.8982
S	2	3	88.00	-0.8720	0.1164	66	-7.49	<.0001	0.0083	-1.1887	-0.5553
S	1	2	104.00	-0.2440	0.1182	66	-2.06	0.0430	0.0083	-0.5658	0.07776
S	1	3	104.00	-1.1602	0.1197	66	-9.70	<.0001	0.0083	-1.4859	-0.8345
S	2	3	104.00	-0.9162	0.1194	66	-7.67	<.0001	0.0083	-1.2412	-0.5913
S	1	2	121.00	-0.1392	0.1517	66	-0.92	0.3622	0.0083	-0.5522	0.2737
S	1	3	121.00	-1.1025	0.1554	66	-7.10	<.0001	0.0083	-1.5253	-0.6796
S	2	3	121.00	-0.9632	0.1543	66	-6.24	<.0001	0.0083	-1.3831	-0.5433
S	1	2	136.00	-0.04680	0.1963	66	-0.24	0.8123	0.0083	-0.5810	0.4873
S	1	3	136.00	-1.0515	0.2012	66	-5.23	<.0001	0.0083	-1.5990	-0.5039
S	2	3	136.00	-1.0047	0.1994	66	-5.04	<.0001	0.0083	-1.5472	-0.4621

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the GT at SUTB. In the following program, S represents the travel speed (Speed 1 = 1, Speed 2 = 2, Speed 3 = 3), P represents drawbar power (kW) and Q represents fuel consumption (kg·h^{-1}).

```
DATA GTSUTB;
INPUT S P Q;
CARDS;
1      135.9 34.5
1      137.4 35.1
1      135.9 34.7
1      135.9 34.8
1      120.6 30.7
1      120.4 30.7
1      120.6 30.8
1      121.3 31.0
1      103.7 27.3
1      104.0 27.2
1      103.8 27.1
1      104.2 27.3
1      87.9  24.3
1      87.9  24.1
1      87.8  23.8
1      87.5  24.0
1      70.6  19.9
1      70.8  19.7
1      70.4  19.9
1      70.8  19.7
1      53.0  15.8
1      53.2  16.0
1      53.2  18.4
1      53.4  16.0
2      137.5 34.7
2      138.1 34.8
2      138.4 35.0
2      138.5 35.1
2      120.4 30.9
2      120.7 31.1
2      120.6 30.8
2      120.7 30.8
2      104.8 27.9
2      104.3 27.7
2      104.1 27.5
2      104.4 27.5
2      87.5  24.5
2      87.2  24.1
2      87.5  24.2
2      87.2  24.2
2      70.3  20.4
2      70.5  20.6
2      70.4  20.2
2      70.3  20.1
2      53.0  16.5
2      53.2  16.5
```

```
2      53.3  16.5
2      53.3  16.4
3      134.8 35.6
3      134.5 35.2
3      134.1 35.4
3      134.4 34.8
3      118.2 31.0
3      118.2 31.7
3      119.2 31.6
3      118.9 31.5
3      102.0 28.2
3      102.6 28.0
3      102.3 27.9
3      102.1 27.7
3      85.1  25.1
3      85.3  24.7
3      85.1  24.6
3      85.1  24.9
3      68.4  21.0
3      68.5  20.7
3      68.4  20.9
3      68.5  20.7
3      52.1  17.6
3      52.4  17.1
3      52.1  17.0
3      52.1  17.2
;

PROC PRINT DATA=GTSUTB;
RUN;

PROC GLM DATA=GTSUTB;
  CLASS S;
  MODEL Q=P|S/SOLUTION;
RUN;

PROC MIXED DATA=GTSUTB;
  CLASS S;
  MODEL Q=P|S/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS s/ AT p=53 diff CL alpha=0.0083;
   LSMEANS s/ AT p=70 diff CL alpha=0.0083;
   LSMEANS s/ AT p=88 diff CL alpha=0.0083;
   LSMEANS s/ AT p=104 diff CL alpha=0.0083;
   LSMEANS s/ AT p=121 diff CL alpha=0.0083;
   LSMEANS s/ AT p=136 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the GT at SUTB. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2752.415102	550.483020	3775.27	<.0001
Error	66	9.623648	0.145813		
Corrected Total	71	2762.038750			

R-Square	Coeff Var	Root MSE	Q Mean
0.996516	1.477432	0.381854	25.84583

The Mixed Procedure

Solution for Fixed Effects

Effect	S	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		6.0502	0.2695	66	22.45	<.0001
P		0.2160	0.002759	66	78.32	<.0001
S	1	-1.3900	0.3838	66	-3.62	0.0006
S	2	-0.8577	0.3811	66	-2.25	0.0278
S	3	0	.	.	.	.
P*S	1	0.002691	0.003892	66	0.69	0.4916
P*S	2	-0.00118	0.003858	66	-0.31	0.7610
P*S	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	18751.6	<.0001
S	2	66	61.83	<.0001
P*S	2	66	0.53	0.5918

Differences of Least Squares Means

Effect	S	_S	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
S	1	2	53.00	-0.3271	0.1974	66	-1.66	0.1022	0.0083	-0.8643	0.2101
S	1	3	53.00	-1.2473	0.1955	66	-6.38	<.0001	0.0083	-1.7793	-0.7153
S	2	3	53.00	-0.9202	0.1946	66	-4.73	<.0001	0.0083	-1.4499	-0.3904
S	1	2	70.00	-0.2613	0.1477	66	-1.77	0.0815	0.0083	-0.6633	0.1406
S	1	3	70.00	-1.2016	0.1457	66	-8.25	<.0001	0.0083	-1.5981	-0.8050
S	2	3	70.00	-0.9402	0.1454	66	-6.46	<.0001	0.0083	-1.3360	-0.5444
S	1	2	88.00	-0.1917	0.1140	66	-1.68	0.0974	0.0083	-0.5019	0.1186
S	1	3	88.00	-1.1531	0.1131	66	-10.19	<.0001	0.0083	-1.4610	-0.8452
S	2	3	88.00	-0.9614	0.1132	66	-8.49	<.0001	0.0083	-1.2695	-0.6534
S	1	2	104.00	-0.1298	0.1149	66	-1.13	0.2630	0.0083	-0.4426	0.1830
S	1	3	104.00	-1.1100	0.1164	66	-9.54	<.0001	0.0083	-1.4267	-0.7933
S	2	3	104.00	-0.9803	0.1162	66	-8.44	<.0001	0.0083	-1.2964	-0.6642
S	1	2	121.00	-0.06398	0.1475	66	-0.43	0.6658	0.0083	-0.4653	0.3373
S	1	3	121.00	-1.0643	0.1511	66	-7.04	<.0001	0.0083	-1.4755	-0.6531
S	2	3	121.00	-1.0003	0.1502	66	-6.66	<.0001	0.0083	-1.4091	-0.5915
S	1	2	136.00	-0.00593	0.1907	66	-0.03	0.9753	0.0083	-0.5250	0.5132
S	1	3	136.00	-1.0239	0.1957	66	-5.23	<.0001	0.0083	-1.5565	-0.4913
S	2	3	136.00	-1.0180	0.1942	66	-5.24	<.0001	0.0083	-1.5465	-0.4895

SAS program used to perform the statistical analysis on the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the CVT. In the following program, S represents the travel speed (Speed 1 = 1, Speed 2 = 2, Speed 3 = 3), P represents drawbar power (kW) and Q represents fuel consumption (kg·h^{-1}).

```
DATA IVT;
INPUT S P Q;
CARDS;
1      135.5 36.8
1      135.6 36.9
1      135.8 36.9
1      136.2 37.6
1      120.8 33.0
1      120.9 33.0
1      120.9 33.4
1      120.9 33.2
1      103.9 27.6
1      104.1 27.7
1      104.0 27.6
1      103.9 27.6
1      87.6  23.6
1      87.6  23.8
1      87.8  23.2
1      87.9  24.0
1      70.5  20.7
1      70.6  21.2
1      70.5  21.2
1      70.6  20.7
1      53.2  16.2
1      53.3  16.2
1      53.1  16.0
1      53.1  16.0
2      138.1 37.7
2      138.1 37.3
2      138.9 37.7
2      138.4 37.3
2      121.0 33.3
2      120.7 33.2
2      120.8 33.2
2      121.1 33.3
2      104.5 28.4
2      104.6 28.5
2      104.3 28.4
2      104.5 28.2
2      87.6  24.3
2      87.7  24.1
2      87.9  24.4
2      87.7  24.2
2      70.3  22.1
2      70.0  21.8
2      70.2  21.7
2      70.3  21.4
2      52.9  16.7
2      53.0  16.7
```

```
2       52.8   16.9
2       52.6   16.7
3       134.4  37.5
3       134.0  37.6
3       134.6  37.6
3       134.7  37.9
3       118.3  34.1
3       118.9  33.8
3       118.7  34.3
3       119.0  34.1
3       102.2  29.3
3       102.4  29.2
3       102.5  28.8
3       102.3  30.3
3       85.1   24.9
3       85.5   24.6
3       85.4   24.3
3       84.9   24.4
3       69.0   22.5
3       68.9   22.7
3       68.6   22.5
3       68.5   22.6
3       51.2   17.5
3       51.3   17.5
3       51.5   17.7
3       51.2   17.5
;

PROC PRINT DATA=IVT;
RUN;

PROC GLM DATA=IVT;
  CLASS S;
  MODEL Q=P|S/SOLUTION;
RUN;

PROC MIXED DATA=IVT;
  CLASS S;
  MODEL Q=P|S/SOLUTION OUTP=resout HTYPE=1;
   LSMEANS s/ AT p=53 diff CL alpha=0.0083;
   LSMEANS s/ AT p=70 diff CL alpha=0.0083;
   LSMEANS s/ AT p=88 diff CL alpha=0.0083;
   LSMEANS s/ AT p=104 diff CL alpha=0.0083;
   LSMEANS s/ AT p=121 diff CL alpha=0.0083;
   LSMEANS s/ AT p=136 diff CL alpha=0.0083;
RUN;
```

Results of the SAS statistical analysis of the data from the drawbar performance tests on the John Deere 8295R PST and John Deere 8295R IVT tractors for the CVT. Results shown include the ANOVA table for the test of the main effects, the line fit statistics, estimates for the coefficients of the best fit line and the tests of the differences of the least square means.

The GLM Procedure

Dependent Variable: Q

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3497.507917	699.501583	1472.02	<.0001
Error	66	31.363194	0.475200		
Corrected Total	71	3528.871111			

R-Square	Coeff Var	Root MSE	Q Mean
0.991112	2.552088	0.689347	27.01111

The Mixed Procedure

Solution for Fixed Effects

Effect	S	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		5.2048	0.4834	66	10.77	<.0001
P		0.2400	0.004948	66	48.50	<.0001
S	1	-2.6400	0.6913	66	-3.82	0.0003
S	2	-1.0635	0.6839	66	-1.56	0.1247
S	3	0	.	.	.	.
P*S	1	0.01023	0.007012	66	1.46	0.1493
P*S	2	-0.00146	0.006917	66	-0.21	0.8337
P*S	3	0	.	.	.	.

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
P	1	66	7281.68	<.0001
S	2	66	37.53	<.0001
P*S	2	66	1.67	0.1968

Differences of Least Squares Means

Effect	S	_S	P	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
S	1	2	53.00	-0.9569	0.3558	66	-2.69	0.0090	0.0083	-1.9251	0.01130
S	1	3	53.00	-2.0977	0.3521	66	-5.96	<.0001	0.0083	-3.0559	-1.1395
S	2	3	53.00	-1.1408	0.3498	66	-3.26	0.0018	0.0083	-2.0929	-0.1887
S	1	2	70.00	-0.7582	0.2664	66	-2.85	0.0059	0.0083	-1.4831	-0.03328
S	1	3	70.00	-1.9238	0.2626	66	-7.33	<.0001	0.0083	-2.6384	-1.2092
S	2	3	70.00	-1.1656	0.2619	66	-4.45	<.0001	0.0083	-1.8782	-0.4529
S	1	2	88.00	-0.5478	0.2058	66	-2.66	0.0097	0.0083	-1.1078	0.01218
S	1	3	88.00	-1.7396	0.2041	66	-8.52	<.0001	0.0083	-2.2951	-1.1841
S	2	3	88.00	-1.1918	0.2043	66	-5.83	<.0001	0.0083	-1.7478	-0.6358
S	1	2	104.00	-0.3608	0.2075	66	-1.74	0.0867	0.0083	-0.9254	0.2038
S	1	3	104.00	-1.5759	0.2102	66	-7.50	<.0001	0.0083	-2.1479	-1.0039
S	2	3	104.00	-1.2151	0.2095	66	-5.80	<.0001	0.0083	-1.7854	-0.6448
S	1	2	121.00	-0.1621	0.2660	66	-0.61	0.5444	0.0083	-0.8859	0.5618
S	1	3	121.00	-1.4020	0.2728	66	-5.14	<.0001	0.0083	-2.1444	-0.6595
S	2	3	121.00	-1.2399	0.2703	66	-4.59	<.0001	0.0083	-1.9756	-0.5043
S	1	2	136.00	0.01328	0.3439	66	0.04	0.9693	0.0083	-0.9226	0.9492
S	1	3	136.00	-1.2485	0.3531	66	-3.54	0.0007	0.0083	-2.2096	-0.2874
S	2	3	136.00	-1.2618	0.3489	66	-3.62	0.0006	0.0083	-2.2114	-0.3121

Appendix C: Data used for Pilot Study

Table C.1: Average values for the north side of the test track from max power data from 20 tractors tested in 2008 and 2009.

Test Number & Tractor Model	North Averages					
	Drawbar Power (kW)	Drawbar Pull (kN)	Travel Speed (km·h^{-1})	Engine Speed (rpm)	Slip (%)	Fuel Rate (kg·h^{-1})
1928 AGCO MT945B	242.85	126.15	6.93	2098	2.56	74.22
1929 AGCO MT955B	270.69	141.78	6.87	2093	3.33	79.50
1930 AGCO MT965B	295.63	154.98	6.87	2100	3.66	89.57
1931 AGCO MT975B	347.08	142.67	8.76	2099	2.97	105.65
1933 MF 5480	76.98	29.73	9.32	2199	3.39	26.10
1921 JD 7130	67.84	25.53	9.56	2298	2.53	21.25
1922 JD 7230	76.32	29.95	9.17	2290	2.10	22.68
1923 JD 7430 IVT	94.76	37.51	9.09	2098	2.66	26.54
1949 JD 6115D	60.38	25.85	8.41	2098	8.71	10.43
1950 JD 6130D	68.34	27.21	9.04	2100	6.41	21.96
1951 JD 6140D	72.00	28.96	8.95	2099	8.83	23.52
1963 JD 8320R	180.03	72.66	8.92	2098	4.23	47.53
1934 NH T9050	294.46	123.07	8.61	1999	3.07%	78.45
1935 NH TV6070	59.72	26.97	7.97	2198	1.60%	27.36
1936 CNH Magnum 335	181.02	89.14	7.31	2099	3.50%	53.31
1937 NH T8050	174.72	90.45	6.95	2214	4.47%	53.50
1926 JD 9630	318.79	131.68	8.72	2100	3.09%	87.60
1940 JD 9230	180.29	85.46	7.59	2099	3.20%	48.90
1941 JD 9330	225.55	109.64	7.41	2100	3.19%	61.72
1942 JD 9430	255.32	106.40	8.64	2102	4.26%	69.55

Table C.2: Average values for the south side of the test track from max power data from 20 tractors tested in 2008 and 2009.

Test Number & Tractor Model	South Averages					
	Drawbar Power (kW)	Drawbar Pull (kN)	Travel Speed ($km \cdot h^{-1}$)	Engine Speed (rpm)	Slip (%)	Fuel Rate ($kg \cdot h^{-1}$)
1928 AGCO MT945B	243.09	126.26	6.93	2098	2.61	74.39
1929 AGCO MT955B	270.64	141.79	6.87	2093	3.36	79.74
1930 AGCO MT965B	294.96	154.72	6.86	2098	3.62	89.41
1931 AGCO MT975B	347.30	142.88	8.75	2098	3.05	105.64
1933 MF 5480	76.88	29.71	9.32	2199	3.36	25.94
1921 JD 7130	67.81	25.57	9.55	2292	2.53	21.48
1922 JD 7230	76.45	30.09	9.15	2285	2.19	22.22
1923 JD 7430 IVT	94.51	37.44	9.09	2096	2.64	26.79
1949 JD 6115D	60.40	25.82	8.42	2102	8.82	10.68
1950 JD 6130D	68.15	27.19	9.02	2100	6.44	21.80
1951 JD 6140D	72.17	29.01	8.96	2098	8.55	23.48
1963 JD 8320R	179.78	72.53	8.93	2098	4.28	45.09
1934 NH T9050	297.88	124.53	8.61	1996	2.96%	78.51
1935 NH TV6070	59.95	27.09	7.97	2199	1.49%	27.43
1936 CNH Magnum 335	182.30	89.83	7.31	2097	4.05%	53.39
1937 NH T8050	175.07	90.44	6.97	2201	3.69%	53.51
1926 JD 9630	317.20	131.28	8.70	2099	3.21%	87.94
1940 JD 9230	180.53	85.60	7.59	2099	3.20%	48.74
1941 JD 9330	224.57	109.38	7.39	2101	3.43%	61.60
1942 JD 9430	256.32	106.76	8.64	2102	4.18%	69.33

Table C.3: Percent differences in values from south side of the test track compared to values from the north side of the track from max power data from 20 tractors tested in 2008 and 2009. Calculated statistics from two-tailed t-test are also shown.

Test Number & Tractor Model	Percent Difference of South from North (in decimal form)					
	Drawbar Power (%)	Drawbar Pull (%)	Travel Speed (%)	Engine Speed (%)	Slip (%)	Fuel Rate (%)
1928 AGCO MT945B	-0.00097	-0.00090	-0.00007	-0.00018	-0.01734	-0.00227
1929 AGCO MT955B	0.00020	-0.00011	0.00030	-0.00018	-0.00895	-0.00302
1930 AGCO MT965B	0.00226	0.00164	0.00063	0.00063	0.00835	0.00177
1931 AGCO MT975B	-0.00062	-0.00149	0.00087	0.00046	-0.02853	0.00000
1933 MF 5480	0.00126	0.00084	0.00041	0.00039	0.00846	0.00616
1921 JD 7130	0.00045	-0.00155	0.00200	0.00238	-0.00311	-0.01079
1922 JD 7230	-0.00174	-0.00461	0.00285	0.00206	-0.04406	0.02053
1923 JD 7430 IVT	0.00263	0.00188	0.00074	0.00071	0.00865	-0.00937
1949 JD 6115D	-0.00026	0.00115	-0.00140	-0.00178	-0.01264	-0.02417
1950 JD 6130D	0.00283	0.00046	0.00236	0.00025	-0.00551	0.00761
1951 JD 6140D	-0.00237	-0.00192	-0.00046	0.00023	0.03142	0.00158
1963 JD 8320R	0.00139	0.00180	-0.00060	0.00000	-0.01102	0.05128
1934 NH T9050	-0.01161	-0.01189	0.00025	0.00149	0.03763	-0.00086
1935 NH TV6070	-0.00389	-0.00440	0.00050	-0.00056	0.06511	-0.00239
1936 CNH Magnum 335	-0.00709	-0.00766	0.00057	0.00104	-0.15714	-0.00147
1937 NH T8050	-0.00199	0.00012	-0.00211	0.00580	0.17404	-0.00017
1926 JD 9630	0.00500	0.00304	0.00197	0.00071	-0.03939	-0.00395
1940 JD 9230	-0.00132	-0.00156	0.00024	0.00018	-0.00180	0.00332
1941 JD 9330	0.00431	0.00241	0.00190	-0.00056	-0.07448	0.00190
1942 JD 9430	-0.00393	-0.00337	-0.00056	0.00021	0.01731	0.00314
Mean:	-0.00077	-0.00131	0.00052	0.00066	-0.00265	0.00194
Standard Deviation:	0.00388	0.00367	0.00125	0.00152	0.06180	0.01438
t-statistic:	-0.88968	-1.59000	1.85446	1.95086	-0.19173	0.60365
Critical Value ($t_{0.025,19}$):	2.093	2.093	2.093	2.093	2.093	2.093
Conclusion:	No Sig Dif	No Sig Dif	No Sig Dif	No Sig Dif	No Sig Dif	No Sig Dif

Appendix D: Raw Data

Table D.1: Raw data obtained on June 3, 2010, from testing the JD 8295R PST at full engine speed.

Speed Designation	Percent Load (%)	Replication	Start Time	Engine Speed (rpm)	Drawbar Power (kW)	Drawbar Pull (kN)	Travel Speed (km·h^{-1})	Wheel Slip (%)	Fuel Consumption (kg·h^{-1})	Fuel Inlet Temp (°C)	Coolant Temp (°C)
1	30	1	6/3/2010 8:11	2180	53.1	32.22	5.94	1.19	20.7	46.5	82.6
1	50	1	6/3/2010 8:21	2169	87.7	53.90	5.86	2.13	26.9	40.9	83.7
1	80	1	6/3/2010 8:30	2155	136.3	85.56	5.73	3.77	36.7	39.9	86.3
1	60	1	6/3/2010 8:37	2164	103.8	64.34	5.80	2.78	30.5	40.7	84.3
1	40	1	6/3/2010 8:44	2175	70.3	43.06	5.88	2.26	23.7	41.3	75.3
1	70	1	6/3/2010 8:50	2158	121.2	75.49	5.78	3.10	34.2	40.7	84.6
2	60	1	6/3/2010 9:00	2163	104.3	47.95	7.84	1.96	30.9	41.2	84.0
2	80	1	6/3/2010 9:08	2155	137.4	63.86	7.75	2.77	36.9	41.3	90.2
2	70	1	6/3/2010 9:15	2159	121.2	56.01	7.79	2.28	34.1	43.4	89.7
2	40	1	6/3/2010 9:20	2175	70.3	31.95	7.93	1.49	23.4	44.4	79.7
2	30	1	6/3/2010 9:29	2178	53.0	23.96	7.97	1.25	21.3	43.7	71.2
2	50	1	6/3/2010 9:34	2167	87.3	39.88	7.88	1.78	28.3	42.6	74.1
3	40	1	6/3/2010 9:42	2174	68.7	23.36	10.58	1.02	24.2	41.9	81.6
3	70	1	6/3/2010 9:44	2158	118.9	40.99	10.44	1.32	34.7	42.0	84.4
3	50	1	6/3/2010 10:34	2167	85.8	29.38	10.52	0.99	28.2	43.2	83.7
3	80	1	6/3/2010 10:39	2153	134.4	46.58	10.39	2.02	37.6	43.6	89.8
3	30	1	6/3/2010 10:45	2178	52.3	17.76	10.61	0.59	21.1	44.2	77.1
3	60	1	6/3/2010 10:50	2161	102.3	35.18	10.47	1.72	31.5	44.3	84.1
1	50	2	6/3/2010 10:56	2169	87.5	53.86	5.85	2.37	26.3	45.4	79.6
1	70	2	6/3/2010 10:59	2158	120.7	75.48	5.76	3.26	33.8	45.1	85.0
1	60	2	6/3/2010 11:02	2163	103.8	64.30	5.82	2.47	30.3	44.7	87.3
1	30	2	6/3/2010 11:05	2180	53.3	32.30	5.94	1.11	19.5	45.3	81.5
1	80	2	6/3/2010 11:09	2154	136.0	85.94	5.71	4.15	36.8	46.0	84.7
1	40	2	6/3/2010 11:12	2175	70.5	43.02	5.90	1.84	23.4	46.3	83.4
3	50	2	6/3/2010 11:20	2168	85.4	29.20	10.53	0.99	27.5	45.9	83.4
3	70	2	6/3/2010 11:23	2158	118.9	40.99	10.44	1.36	34.5	45.2	85.3
3	30	2	6/3/2010 11:26	2179	51.6	17.49	10.63	0.43	20.4	44.9	80.8
3	80	2	6/3/2010 11:28	2154	134.8	46.74	10.38	1.74	37.4	44.9	83.5
3	40	2	6/3/2010 11:30	2174	68.5	23.30	10.59	0.82	24.2	45.3	84.4
3	60	2	6/3/2010 11:32	2162	101.6	34.96	10.46	1.92	31.3	45.4	84.4
2	50	2	6/3/2010 11:37	2169	87.2	39.89	7.87	1.67	26.4	46.8	80.4
2	30	2	6/3/2010 11:41	2179	52.7	23.83	7.96	1.21	20.0	46.6	79.5

2	40	2	6/3/2010 11:44	2175	70.6	32.03	7.93	1.19	23.4	45.8	78.4
2	60	2	6/3/2010 11:47	2163	104.3	47.92	7.83	1.90	30.9	45.7	82.6
2	70	2	6/3/2010 11:49	2158	120.9	55.88	7.79	1.97	34.2	45.5	87.4
2	80	2	6/3/2010 11:54	2154	138.0	64.05	7.76	2.52	36.9	46.0	93.4
1	40	3	6/3/2010 12:49	2175	70.5	43.00	5.91	1.69	23.1	45.3	82.3
1	80	3	6/3/2010 12:53	2155	136.0	85.88	5.70	4.16	37.0	45.7	86.8
1	70	3	6/3/2010 12:56	2158	120.6	75.54	5.75	3.64	33.9	46.0	89.8
1	50	3	6/3/2010 12:59	2170	87.7	54.01	5.84	2.41	26.3	47.0	87.6
1	60	3	6/3/2010 13:02	2164	104.0	64.40	5.82	2.88	30.3	47.7	87.8
1	30	3	6/3/2010 13:06	2181	53.3	32.34	5.93	1.37	19.4	48.0	83.0
2	40	3	6/3/2010 13:16	2175	70.5	32.00	7.93	1.24	23.4	47.6	83.5
2	80	3	6/3/2010 13:18	2154	138.2	64.21	7.75	2.89	37.6	46.9	88.0
2	50	3	6/3/2010 13:23	2169	87.3	39.93	7.87	1.72	26.8	47.1	87.1
2	60	3	6/3/2010 13:25	2163	104.6	48.03	7.85	2.10	30.6	47.4	87.8
2	30	3	6/3/2010 13:28	2180	53.1	□3.9	7.97	0.93	20.1	48.1	84.4
2	70	3	6/3/2010 13:30	2158	120.9	55.94	7.78	2.57	34.2	48.2	86.4
3	30	3	6/3/2010 13:37	2179	52.3	17.70	10.64	0.58	20.5	48.3	80.3
3	80	3	6/3/2010 13:39	2154	135.4	46.90	10.40	2.03	37.4	47.9	84.7
3	60	3	6/3/2010 13:41	2163	102.5	35.17	10.49	1.28	31.3	48.0	89.8
3	50	3	6/3/2010 13:42	2168	84.4	28.87	10.53	1.12	27.3	47.6	89.1
3	40	3	6/3/2010 13:45	2173	68.5	23.35	10.57	1.51	23.9	48.2	85.7
3	70	3	6/3/2010 13:48	2158	118.7	40.97	10.43	1.92	34.5	48.5	87.7
3	30	4	6/3/2010 13:51	2179	51.9	17.54	10.66	0.73	20.6	49.3	86.3
3	80	4	6/3/2010 13:55	2154	134.1	46.32	10.42	1.32	37.4	49.3	90.8
3	40	4	6/3/2010 13:58	2174	68.5	23.29	10.59	1.01	23.5	48.9	88.3
3	70	4	6/3/2010 14:00	2158	118.6	40.85	10.45	1.29	34.4	49.1	88.3
3	60	4	6/3/2010 14:02	2163	101.4	34.91	10.45	2.16	31.3	49.3	91.4
3	50	4	6/3/2010 14:04	2168	85.2	29.10	10.55	1.16	27.4	49.0	90.5
2	30	4	6/3/2010 14:09	2180	53.1	23.98	7.97	0.90	19.8	51.2	80.5
2	80	4	6/3/2010 14:12	2154	137.9	64.01	7.76	2.75	37.2	50.7	85.3
2	60	4	6/3/2010 14:14	2163	104.4	47.94	7.85	1.86	30.7	49.1	90.8
2	40	4	6/3/2010 14:19	2175	70.5	32.02	7.93	1.38	23.2	49.5	85.5
2	70	4	6/3/2010 14:23	2159	121.0	55.78	7.81	2.26	34.2	49.9	89.6
2	50	4	6/3/2010 14:26	2169	87.2	39.93	7.87	2.00	26.7	50.0	90.2
1	80	4	6/3/2010 14:36	2154	135.8	85.84	5.70	4.42	36.8	50.1	94.1
1	50	4	6/3/2010 14:42	2169	87.6	53.88	5.85	2.44	26.3	50.6	87.8
1	70	4	6/3/2010 14:46	2158	120.8	75.57	5.75	3.57	34.1	51.2	90.0
1	30	4	6/3/2010 14:52	2181	53.4	32.29	5.95	1.02	19.3	51.9	80.7
1	60	4	6/3/2010 14:55	2164	103.8	64.43	5.80	2.82	30.3	51.5	83.7
1	40	4	6/3/2010 14:59	2175	70.5	43.04	5.90	1.45	22.9	50.9	85.3

Table D.2: Raw data obtained on June 4, 2010, from testing the JD 8295R PST at reduced engine speed and shifted up two gears.

Speed Designation	Percent Load (%)	Replication	Start Time	Engine Speed (rpm)	Drawbar Power (kW)	Drawbar Pull (kN)	Travel Speed ($km \cdot h^{-1}$)	Wheel Slip (%)	Fuel Consumption ($kg \cdot h^{-1}$)	Fuel Inlet Temp (°C)	Coolant Temp (°C)
3	30	1	6/4/2010 7:27	1627	52.1	17.64	10.62	0.67	17.6	42.8	79.8
3	80	1	6/4/2010 7:33	1611	134.8	46.60	10.41	1.82	35.6	42.5	96.7
3	50	1	6/4/2010 7:36	1614	85.1	29.31	10.45	1.82	25.1	41.5	92.6
3	70	1	6/4/2010 7:38	1601	118.2	41.00	10.38	0.84	31.0	41.6	93.4
3	40	1	6/4/2010 7:42	1621	68.4	23.33	10.56	0.84	21.0	42.0	91.1
3	60	1	6/4/2010 7:45	1607	102.0	35.20	10.43	1.48	28.2	42.2	91.8
2	40	1	6/4/2010 7:55	1632	70.3	31.95	7.92	1.31	20.4	42.5	82.0
2	70	1	6/4/2010 7:57	1613	120.4	55.83	7.77	2.20	30.9	42.2	85.8
2	80	1	6/4/2010 8:05	1615	137.5	63.90	7.75	2.59	34.7	42.7	94.9
2	30	1	6/4/2010 8:07	1633	53.0	24.01	7.94	1.08	16.5	42.5	88.4
2	60	1	6/4/2010 8:12	1624	104.8	48.15	7.84	1.91	27.9	42.8	89.6
2	50	1	6/4/2010 8:14	1631	87.5	39.93	7.89	1.59	24.5	43.2	90.9
1	40	1	6/4/2010 8:21	1627	70.6	42.98	5.91	1.56	19.9	46.0	81.2
1	50	1	6/4/2010 8:24	1620	87.9	53.98	5.86	1.92	24.3	46.0	83.8
1	80	1	6/4/2010 8:31	1610	135.9	85.37	5.73	3.74	34.5	46.3	96.6
1	30	1	6/4/2010 8:34	1620	53.0	32.31	5.91	1.33	15.8	45.0	89.0
1	70	1	6/4/2010 8:37	1608	120.6	75.53	5.75	3.45	30.7	45.0	89.5
1	60	1	6/4/2010 8:41	1614	103.7	64.36	5.80	2.68	27.3	45.6	94.4
3	70	2	6/4/2010 8:49	1612	118.2	40.95	10.40	2.09	31.7	48.3	90.7
3	80	2	6/4/2010 8:53	1607	134.5	46.62	10.38	1.90	35.2	45.5	96.7
3	50	2	6/4/2010 8:56	1621	85.3	29.09	10.56	0.92	24.7	45.3	93.0
3	40	2	6/4/2010 8:57	1621	68.5	23.38	10.55	1.28	20.7	44.9	91.5
3	60	2	6/4/2010 9:01	1608	102.6	35.53	10.39	1.92	28.0	45.1	93.0
3	30	2	6/4/2010 9:03	1627	52.4	17.74	10.63	1.00	17.1	45.6	90.5
2	40	2	6/4/2010 9:11	1633	70.5	32.05	7.91	1.38	20.6	46.7	81.8
2	30	2	6/4/2010 9:13	1639	53.2	23.95	8.00	0.69	16.5	45.9	81.2
2	70	2	6/4/2010 9:15	1613	120.7	56.00	7.77	2.11	31.1	45.4	85.1
2	80	2	6/4/2010 9:20	1610	138.1	64.46	7.72	2.84	34.8	45.7	96.6
2	50	2	6/4/2010 9:25	1621	87.2	40.00	7.85	1.54	24.1	45.0	91.7
2	60	2	6/4/2010 9:27	1621	104.3	48.02	7.81	1.84	27.7	45.1	93.2
1	60	2	6/4/2010 9:37	1616	104.0	64.37	5.82	2.29	27.2	46.8	91.6
1	70	2	6/4/2010 9:40	1608	120.4	75.47	5.75	3.17	30.7	46.5	95.3

1	40	2	6/4/2010 9:43	1627	70.8	43.11	5.91	1.57	19.7	47.3	90.9
1	30	2	6/4/2010 9:47	1634	53.2	32.20	5.95	1.53	16.0	47.0	85.9
1	50	2	6/4/2010 9:50	1621	87.9	53.98	5.87	1.69	24.1	46.9	85.8
1	80	2	6/4/2010 9:53	1615	137.4	86.20	5.74	3.82	35.1	47.3	94.1
1	30	3	6/4/2010 10:18	1625	53.2	32.34	5.92	1.47	18.4	46.3	84.3
1	60	3	6/4/2010 10:21	1608	103.8	64.66	5.78	2.85	27.1	46.9	88.8
1	40	3	6/4/2010 10:24	1622	70.4	43.03	5.88	1.67	19.9	48.2	88.1
1	80	3	6/4/2010 10:31	1614	135.9	85.32	5.74	3.97	34.7	48.1	96.3
1	50	3	6/4/2010 10:34	1618	87.8	54.08	5.85	2.14	23.8	47.1	92.7
1	70	3	6/4/2010 10:37	1602	120.6	75.75	5.74	3.23	30.8	47.4	93.9
2	80	3	6/4/2010 10:47	1612	138.4	64.61	7.72	2.52	35.0	47.5	95.3
2	70	3	6/4/2010 10:52	1613	120.6	56.06	7.75	2.56	30.8	47.6	93.5
2	50	3	6/4/2010 10:55	1626	87.5	40.00	7.87	1.47	24.2	47.4	92.8
2	40	3	6/4/2010 10:57	1633	70.4	31.97	7.93	1.33	20.2	47.4	91.0
2	30	3	6/4/2010 11:00	1640	53.3	24.03	7.99	1.03	16.5	47.1	86.3
2	60	3	6/4/2010 11:02	1619	104.1	47.94	7.81	1.77	27.5	47.8	87.2
3	40	3	6/4/2010 11:07	1620	68.4	23.33	10.57	0.84	20.9	47.8	87.6
3	70	3	6/4/2010 11:10	1616	119.2	40.97	10.47	1.66	31.6	47.8	94.8
3	80	3	6/4/2010 11:14	1599	134.1	46.80	10.32	1.98	35.4	47.9	95.1
3	60	3	6/4/2010 11:18	1607	102.3	35.36	10.41	1.85	27.9	47.2	93.1
3	50	3	6/4/2010 11:19	1614	85.1	29.18	10.51	1.16	24.6	47.2	92.9
3	30	3	6/4/2010 11:21	1627	52.1	17.63	10.65	0.69	17.0	47.2	89.9
1	70	4	6/4/2010 11:30	1613	121.3	75.68	5.77	3.49	31.0	48.6	94.9
1	60	4	6/4/2010 11:36	1619	104.2	64.42	5.83	2.76	27.3	48.9	94.0
1	40	4	6/4/2010 11:40	1633	70.8	42.93	5.93	1.74	19.7	49.4	91.2
1	80	4	6/4/2010 11:46	1602	135.9	86.05	5.69	3.92	34.8	49.8	95.2
1	30	4	6/4/2010 11:53	1630	53.4	32.36	5.94	1.24	16.0	49.6	85.5
1	50	4	6/4/2010 11:56	1615	87.5	54.03	5.83	2.17	24.0	49.9	86.8
3	30	4	6/4/2010 12:05	1627	52.1	17.64	10.65	1.08	17.2	49.7	83.0
3	70	4	6/4/2010 12:09	1612	118.9	40.93	10.46	1.41	31.5	49.1	91.9
3	50	4	6/4/2010 12:11	1625	85.1	28.96	10.57	1.06	24.9	48.9	94.1
3	80	4	6/4/2010 12:14	1607	134.4	46.56	10.39	1.64	34.8	49.0	95.5
3	40	4	6/4/2010 12:20	1620	68.5	23.33	10.57	1.08	20.7	48.8	89.9
3	60	4	6/4/2010 12:23	1608	102.1	35.26	10.43	1.39	27.7	49.3	94.2
2	30	4	6/4/2010 12:30	1640	53.3	24.05	7.98	1.09	16.4	50.3	83.5
2	80	4	6/4/2010 12:36	1624	138.5	64.15	7.77	2.97	35.1	50.2	97.1
2	50	4	6/4/2010 12:38	1624	87.2	39.96	7.86	1.69	24.2	50.3	93.9
2	60	4	6/4/2010 12:41	1614	104.4	48.21	7.80	2.00	27.5	49.7	93.6
2	70	4	6/4/2010 12:48	1618	120.7	55.75	7.80	2.41	30.8	50.0	93.8
2	40	4	6/4/2010 12:52	1638	70.3	31.89	7.94	1.72	20.1	50.0	89.1

Table D.3: Raw data obtained on June 8, 2010, from testing the JD 8295R IVT in automatic mode.

Speed Designation	Percent Load (%)	Replication	Start Time	Engine Speed (rpm)	Drawbar Power (kW)	Drawbar Pull (kN)	Travel Speed ($km \cdot h^{-1}$)	Wheel Slip (%)	Fuel Consumption ($kg \cdot h^{-1}$)	Fuel Inlet Temp (°C)	Coolant Temp (°C)
2	80	1	6/8/2010 10:18	1831	138.1	63.32	7.85	2.63	37.7	40.0	95.0
2	40	1	6/8/2010 10:23	1356	70.3	31.81	7.95	1.23	22.1	39.6	88.9
2	70	1	6/8/2010 10:27	1705	121.0	55.11	7.90	1.86	33.3	40.0	96.5
2	50	1	6/8/2010 10:32	1455	87.6	39.76	7.93	1.95	24.3	40.3	92.4
2	60	1	6/8/2010 10:37	1505	104.5	47.51	7.92	1.54	28.4	40.3	94.6
2	30	1	6/8/2010 10:41	1200	52.9	23.85	7.99	0.90	16.7	40.3	88.1
3	30	1	6/8/2010 10:46	1262	51.2	17.89	10.32	0.80	17.5	40.3	84.8
3	50	1	6/8/2010 10:49	1434	85.1	29.46	10.40	1.18	24.9	40.4	88.1
3	60	1	6/8/2010 10:53	1535	102.2	35.39	10.40	1.54	29.3	40.5	95.3
3	80	1	6/8/2010 10:57	1817	134.4	46.64	10.38	1.75	37.5	40.2	96.1
3	70	1	6/8/2010 11:00	1770	118.3	41.08	10.36	1.59	34.1	40.5	93.2
3	40	1	6/8/2010 11:05	1365	69.0	23.78	10.44	1.15	22.5	40.5	89.4
1	60	1	6/8/2010 11:14	1478	103.9	65.08	5.75	2.43	27.6	42.1	92.6
1	50	1	6/8/2010 11:18	1439	87.6	54.64	5.78	2.17	23.6	42.3	94.1
1	30	1	6/8/2010 11:24	1200	53.2	32.94	5.82	1.55	16.2	42.5	87.6
1	40	1	6/8/2010 11:31	1299	70.5	43.82	5.79	1.84	20.7	42.6	87.9
1	70	1	6/8/2010 11:38	1682	120.8	76.18	5.71	3.43	33.0	42.9	96.7
1	80	1	6/8/2010 11:44	1788	135.5	85.96	5.68	4.12	36.8	43.3	94.9
1	70	2	6/8/2010 11:49	1675	120.9	76.20	5.71	3.31	33.0	43.5	94.1
1	60	2	6/8/2010 11:54	1479	104.1	65.16	5.75	2.40	27.7	43.6	92.5
1	40	2	6/8/2010 11:57	1351	70.6	43.86	5.80	1.82	21.2	44.1	91.1
1	30	2	6/8/2010 12:03	1200	53.3	32.98	5.82	1.51	16.2	44.4	87.6
1	80	2	6/8/2010 12:10	1785	135.6	86.01	5.67	3.92	36.9	44.7	96.9
1	50	2	6/8/2010 12:14	1445	87.6	54.70	5.77	2.14	23.8	44.3	92.0
3	50	2	6/8/2010 12:34	1438	85.5	29.52	10.42	1.06	24.6	43.1	93.7
3	40	2	6/8/2010 12:38	1361	68.9	23.75	10.44	1.09	22.7	42.5	90.7
3	70	2	6/8/2010 12:42	1711	118.9	41.29	10.36	1.59	33.8	42.8	96.7
3	80	2	6/8/2010 12:45	1837	134.0	46.60	10.35	1.84	37.6	43.0	95.0
3	30	2	6/8/2010 12:50	1219	51.3	17.85	10.36	0.64	17.5	43.5	88.7
3	60	2	6/8/2010 12:56	1533	102.4	35.39	10.42	1.03	29.2	44.8	95.8
2	40	2	6/8/2010 13:04	1352	70.0	31.74	7.94	1.55	21.8	44.8	90.8
2	50	2	6/8/2010 13:06	1403	87.7	39.75	7.94	1.34	24.1	45.2	91.5

2	60	2	6/8/2010 13:08	1496	104.6	47.49	7.93	1.84	28.5	44.9	94.7
2	70	2	6/8/2010 13:13	1698	120.7	55.09	7.89	1.98	33.2	45.8	94.6
2	30	2	6/8/2010 13:18	1200	53.0	23.95	7.96	1.34	16.7	45.7	89.3
2	80	2	6/8/2010 13:23	1796	138.1	63.13	7.87	2.49	37.3	46.4	96.8
1	80	3	6/8/2010 13:29	1790	135.8	86.01	5.68	4.11	36.9	45.6	96.0
1	70	3	6/8/2010 13:35	1678	120.9	76.20	5.71	3.20	33.4	45.6	94.3
1	50	3	6/8/2010 13:42	1387	87.8	54.72	5.78	2.06	23.2	45.0	91.7
1	30	3	6/8/2010 13:45	1200	53.1	32.86	5.82	1.38	16.0	45.2	90.5
1	60	3	6/8/2010 13:49	1484	104.0	65.13	5.75	2.38	27.6	45.4	91.7
1	40	3	6/8/2010 13:52	1355	70.5	43.82	5.79	1.91	21.2	45.7	93.4
2	30	3	6/8/2010 14:00	1200	52.8	23.80	7.99	0.88	16.9	46.3	83.7
2	40	3	6/8/2010 14:02	1335	70.2	31.72	7.97	1.21	21.7	45.9	85.0
2	70	3	6/8/2010 14:07	1697	120.8	55.10	7.89	2.10	33.2	45.6	96.9
2	50	3	6/8/2010 14:11	1453	87.9	39.82	7.94	1.46	24.4	45.7	92.4
2	60	3	6/8/2010 14:14	1495	104.3	47.50	7.90	2.28	28.4	45.8	93.8
2	80	3	6/8/2010 14:16	1794	138.9	63.54	7.87	2.65	37.7	45.7	95.3
3	60	3	6/8/2010 14:21	1510	102.5	35.51	10.40	1.45	28.8	45.4	92.8
3	30	3	6/8/2010 14:30	1207	51.5	17.68	10.50	0.60	17.7	45.0	88.4
3	50	3	6/8/2010 14:33	1428	85.4	29.45	10.44	0.70	24.3	44.8	90.7
3	40	3	6/8/2010 14:37	1362	68.6	23.62	10.46	0.87	22.5	44.8	91.5
3	80	3	6/8/2010 14:41	1835	134.6	46.71	10.37	1.71	37.6	45.5	97.9
3	70	3	6/8/2010 14:43	1788	118.7	41.21	10.37	1.81	34.3	45.8	95.1
2	60	4	6/8/2010 14:48	1507	104.5	47.48	7.93	1.75	28.2	45.9	90.9
2	30	4	6/8/2010 14:50	1224	52.6	23.73	7.98	1.51	16.7	46.4	93.9
2	80	4	6/8/2010 14:53	1769	138.4	63.28	7.88	2.59	37.3	45.8	94.8
2	50	4	6/8/2010 14:57	1449	87.7	39.78	7.94	1.39	24.2	46.4	93.6
2	70	4	6/8/2010 15:00	1688	121.1	55.14	7.91	2.31	33.3	47.0	95.0
2	40	4	6/8/2010 15:02	1376	70.3	31.70	7.98	0.96	21.4	47.1	92.5
1	60	4	6/8/2010 15:08	1486	103.9	65.18	5.74	2.99	27.6	46.8	91.3
1	70	4	6/8/2010 15:15	1678	120.9	76.35	5.70	3.35	33.2	47.3	94.6
1	50	4	6/8/2010 15:18	1451	87.9	54.71	5.79	1.86	24.0	47.8	91.8
1	80	4	6/8/2010 15:24	1796	136.2	86.49	5.67	3.97	37.6	48.1	95.2
1	30	4	6/8/2010 15:28	1202	53.1	32.83	5.82	1.33	16.0	48.0	89.0
1	40	4	6/8/2010 15:31	1301	70.6	43.84	5.80	1.69	20.7	47.5	90.1
3	40	4	6/8/2010 15:38	1358	68.5	23.62	10.44	1.17	22.6	46.8	86.4
3	80	4	6/8/2010 15:43	1832	134.7	46.75	10.38	1.90	37.9	46.1	97.0
3	50	4	6/8/2010 15:47	1427	84.9	29.38	10.40	1.37	24.4	45.9	91.7
3	30	4	6/8/2010 15:53	1209	51.2	17.62	10.47	1.14	17.5	46.0	89.7
3	70	4	6/8/2010 15:58	1762	119.0	41.34	10.36	1.63	34.1	45.9	95.9
3	60	4	6/8/2010 16:00	1677	102.3	35.40	10.40	1.37	30.3	45.9	93.9

Appendix E: Atmospheric Conditions for Duration of Testing

Table E.1: Atmospheric conditions obtained from the Lincoln Municipal Airport, Lincoln, NE, on June 8, 2010, while testing the JD 8295R PST at full engine speed.

Time (CDT)	Temperature (°C)	Dew Point (°C)	Humidity (%)	Barometric Pressure (kPa)	Wind Direction	Wind Speed (km·h^{-1})	Gust Speed (km·h^{-1})
6:54	13.3	11.7	90	101.1	NW	5.6	-
7:54	16.1	12.8	81	101.2	Calm	Calm	-
8:54	18.3	13.3	73	101.1	South	5.6	-
9:54	21.1	15.0	68	101.1	South	11.1	-
10:54	23.3	15.0	59	101.0	SSW	16.7	-
11:54	24.4	14.4	54	100.9	SSW	16.7	-
12:54	25.6	15.6	54	100.9	South	16.7	25.9
13:54	26.7	15.6	50	100.8	SSE	18.5	25.9
14:54	26.7	15.6	50	100.7	South	24.1	-
15:54	28.3	16.7	49	100.6	South	25.9	-

Table E.2: Atmospheric conditions obtained from the Lincoln Municipal Airport, Lincoln, NE, on June 8, 2010, while testing the JD 8295R PST at reduced engine speed and shifted up two gears.

Time (CDT)	Temperature (°C)	Dew Point (°C)	Humidity (%)	Barometric Pressure (kPa)	Wind Direction	Wind Speed (km·h^{-1})	Gust Speed (km·h^{-1})
6:54	20.6	18.9	90	100.5	Calm	Calm	-
7:54	22.8	18.9	79	100.5	Calm	Calm	-
8:54	24.4	18.3	69	100.5	WSW	14.8	-
9:54	26.1	18.3	62	100.6	WSW	14.8	-
10:54	26.7	18.3	60	100.5	West	11.1	-
11:54	27.2	18.9	60	100.5	Calm	Calm	-
12:54	27.8	19.4	60	100.5	Calm	Calm	-
13:54	30.0	20.0	55	100.5	Variable	5.6	-

Table E.3: Atmospheric conditions obtained from the Lincoln Municipal Airport, Lincoln, NE, on June 8, 2010, while testing the JD 8295R PST IVT in automatic mode.

Time (CDT)	Temperature (°C)	Dew Point (°C)	Humidity (%)	Barometric Pressure (kPa)	Wind Direction	Wind Speed (km·h^{-1})	Gust Speed (km·h^{-1})
9:54	21.1	18.9	87	101.0	West	16.7	-
10:11	21.0	19.0	88	101.1	WNW	18.5	-
10:54	22.8	18.3	76	101.1	WNW	25.9	42.6
11:08	24.0	18.0	69	101.2	West	31.5	44.4
11:54	25.6	17.8	62	101.0	West	27.8	-
12:54	26.1	18.3	62	100.9	NW	20.4	-
13:54	26.7	19.4	64	101.0	NW	18.5	-
14:54	26.1	18.9	64	101.0	NW	13.0	-
15:54	26.7	18.9	62	101.0	NW	18.5	-
16:54	26.7	17.8	58	101.0	North	27.8	-